Student Designed Science Games: A Study of the Design Process, Artifacts, and Attitudes in a Constructivist and Constructionist Learning Environment

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DEDICATION

I dedicate this to my family, for your love and support: my mother and father, Lili and Ahmad; my husband, Brian; my sons, Alex and Elliott.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

STUDENT DESIGNED SCIENCE GAMES: A STUDY OF THE DESIGN PROCESS, ARTIFACTS, AND ATTITUDES IN A CONSTRUCTIVIST AND CONSTRUCTIONIST LEARNING ENVIRONMENT

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Video games as pedagogy is an interest to the educational research community, both in creating games for learning and for learning through creating games. This research study takes the latter approach, putting students in charge of creating their own video games based on science topics with which they were previously unfamiliar. It provided the opportunity for students to learn about and explore their understanding of the topics while designing their games. Students worked closely with a scientist from the Federation of American Scientists (FAS), who also had experience in the design of educational science games. The purpose of this study was to follow the design process students undertook when placed in a constructivist and constructionist learning environment with available tools and support to complete their games.

This study furthermore examined student attitudes towards science and technology (specifically, making video games) after participation in the game design workshop. Science, Technology, Engineering, and Mathematics (STEM) skills are predicted to be necessary for a technologically-oriented future with an increasingly competitive global market. Engaging students in STEM activities can encourage them towards these fields. Thus, programs such as the game design workshop in this study grant the opportunity to stimulate student interest.

A mixed methods approach was used in this study, applying both qualitative and quantitative analysis on the data. Qualitative findings highlight student strategies during the design process, including modeling their games on video games with which they were already familiar, gathering information through design journals, web queries, and discussions with a science expert, and working collaboratively. The study also found that student understanding of the science topic began to take shape and evolve as their game designs evolved, and that the game design process helped students articulate this understanding of the topic. Quantitative analysis on surveys did not show any statistical significance on improvement of science attitudes. With regards to attitudes towards making video games, students did show an improvement with statistical significance regarding their perceived ability at making video games.

1. INTRODUCTION

Kids love playing video games. A study from the PEW Internet and American Life Project found that 97% of American teenagers ages 12-17 play video games, whether on the Internet, computers, portable devices, or gaming systems (Lenhart et al., 2008). Furthermore, this love of playing video games is shared amongst both boys and girls, with 99% and 94% playing respectively, and game play practices do not vary across racial and ethnicity groups or different socioeconomic levels. A survey of American students in grades K-12 found that, on average across the grades, students are playing video games 8-10 hours a week (Project Tomorrow, 2008). The entertainment industry can certainly back up this claim, as video game sales in the United States made over $15.4 billion in 2013 (Entertainment Software Association, 2014). This keen interest in and commitment given to video games has caused researchers and educators to examine how these games attract their audience and how this can be applicable for learning.

Background

It is suggested that beyond the entertainment value, video games are becoming more complex and challenging, placing the player into rich learning environments where they are asked to think, problem solve and, often times, collaborate (Gee, 2003; 2012; Shaffer & Gee, 2012; Squire, 2011; Squire, Giovanetto, Devane, & Durga, 2005). Game players learn new game skills and strategies though a series of levels that increasingly become more difficult, asking the player to draw from knowledge gained from previous levels in order to advance (Lim, 2008; Prensky, 2007). The designers of these games must find a way to get the players to want to learn how to play and stay engaged throughout the challenges, a problem similar to that which a school teacher faces (Becker, 2007; Gee, 2003, 2007). In fact, Prensky (2007) suggests that the designers of educational curriculum would do well to learn from the designers of video games. This kind of thinking about video games and education is based on learning *from* these games that are already engrained into lives of the students outside of school and finding ways to meaningfully incorporate them inside their educational setting.

Video Games for Education

One of the ways that video games are being examined for this purpose is through the creation of educational games. Educational games are emerging as a popular area of development, hoping the entertaining features of the games will motivate learning (Danielsson & Wiberg, 2006). These types of games have fallen under the category of "edutainment," often associated with a negative connotation due to the many drill-based and poorly designed educational games on the market (Gros, 2007; Lim, 2008; Prensky, 2007). A summit on Educational Games, sponsored by the Federation of American Scientists (FAS), the Entertainment Software Association, and the National Science Foundation, issued a report stating that educational games had the potential to be useful for high quality education, but that the games must be "built on the science of learning" (FAS, 2006, p. 5). Some researchers argue that there are already commercial entertainment games available that embody good learning principles, which is much of the reason they are so engaging (Becker, 2007; Gee, 2007). Yet Becker (2007) states that designing games for learning is a big challenge for instructional designers. One of these challenges is that the games designed for learning simply turn out to be “boring,” a side effect that Prensky (2007) says is a result of adults creating games without any input from the intended audience, kids. Druin (2002) states that children’s input on designing technology allows the thinking to be moved away from traditional methods and can ultimately have an effect on the way the technology is used for teaching and learning. Indeed, research studies have looked at incorporating children of all ages during various stages of technology design processes (Druin, 2002; Flannery et al., 2013; Friedman & Saponara, 2008) including giving them role of video game designers.

Defining Video Games

The term “video games” which will be used in this study refers to any type of digital game, whether it is played on a gaming console such as an Xbox or Nintendo system, online through a web browser, on a portable device such as a cell phone, or on a computer. The video game artifacts that are created by students throughout the literature are mostly computer-based, created through programming languages, software packages such as Adobe Flash, or special software tools designed specifically to help in game creation.

Children as Designers

Before students were given the opportunity to be the creators of video games, they had to be given the opportunity to work with computers. In his 1980 book *Mindstorms,* Seymour Papert, one of the creators of the programming language LOGO, writes of children interacting with the computer and learning math through programming. This was done by writing commands in LOGO to make a turtle object on the computer screen to move, causing the turtle (cursor) to draw a line in its trail, thereby creating geometric shapes on the computer screen. These children were taught methods on how to work with the turtle and the language, rather than given explicit instructions on how, for instance, to draw a circle, so that they could explore the environment on their own. Papert looked at this as the “child as a builder,” taken from the theories of Jean Piaget which include “children as builders of their own intellectual structures” (Papert, 1980, p. 7). This is the underlying theory of constructivism, which is built upon learners creating their own knowledge through their experiences. Papert (1991) takes this further with the idea of *constructionism*, which relies on building knowledge structures while engaging in creating, or constructing, some kind of entity, such as a turtle moving in specific directions to create a square. According to constructionism, the children are creating a square on the screen by typing in LOGO commands, and simultaneously building their understanding of a square through its creation.

Kafai (1995), using Papert’s ideas of constructionism, studied fourth-grade students creating video games about fractions using the LOGO programming language. This study and the preceding work based on children constructing instructional software (Harel, 1990) brought attention to the concept of students as designers of multimedia products, specifically video games, and outlined the constructivist learning environment in which students were immersed. This will be further discussed in Chapter 2.

The idea of children-as-designers with respect to learning and technology began in the 1970s, but is even more relevant today. The advancement of technology has made electronics and software more readily affordable and accessible, more sophisticated in graphics and ease of usability, and the wealth of information available on the Internet offers free tutorials and message support boards to help users. Whereas Papert (1980) was first introducing fifth-graders to text-based programming on a computer and trying to persuade others that this was a good idea, today's younger generation has multiple digital media manipulation and creation tools available to them that are aimed specifically for their age groups. For example, some free game design programs include Game Maker, Scratch, and Storytelling Alice, all of which take basic programming concepts and make them more understandable by incorporating icons and drag-and-drop moves for users to be able to create their own projects. Researchers who have introduced these programs to K-12 students have found that the students are motivated and engaged in creating their projects, collaborate with others, and learn valuable game design skills (Kafai & Peppler, 2012; Kelleher & Pausch, 2006; Robertson & Nicholson, 2007; Sheridan, Clark, & Peters, 2009).

Technology and the Future Economy

Encouraging kids to follow this excitement about working with and learning about technology is becoming one of the nation's biggest concerns. The report *Rising Above the Gathering Storm* found that the United States is lagging behind in science and technology development and that this needs to change in order for the U.S. workforce to remain competitive in the global economy (U.S. Senate Report, 2006). Revisiting this report five years later has found the outlook to have worsened, while other countries are making continued growth in these areas (National Academy of Science, National Academy of Engineering, & Institute of Medicine, 2010). Encouraging interest in science, technology, engineering, and mathematics (STEM) fields has become a national initiative in order to foster the education of our children and help develop future innovators (National Science Foundation, 2009). Atkinson, Hugo, Lundgren, Shapiro, and Thomas (2007) claim that the economy is specifically becoming more based on science and technology. Lawrenz, Huffman, and Thomas (2006) note, "It is important for all students, including those who have not traditionally been able to participate in STEM fields, to have opportunities to learn the knowledge and skills they will need in a technologically oriented future" (p. 105). The National Science and Technology Council (2012) issued a report establishing a five-year plan to encourage and fund STEM programs in order to prepare students with the skills needed to be successful in the 21st century economy. The term "21st century skills" is found throughout the literature to describe what students today need to learn in order to prepare for the global economy, although there is no one set list of qualities. The Partnership for 21st Century Skills issued a report that includes such abilities as "thinking critically and making judgments," "solving complex, multidisciplinary, open-ended problems," "communicating and collaborating," and "making innovative use of knowledge, information and opportunities" (2008, p. 10).

Students themselves share in this assessment. In a survey of students from grades 3-12, students rated "good tech skills" as the number one skill they felt was necessary in order to succeed in the 21^{st} century, which includes 74% of high school students (Project Tomorrow, 2008). Yet, only 19% of these students said they would be interested in a job in the STEM fields, with another one third of the students saying they could be further interested if they understood what jobs in the STEM fields entailed (Project Tomorrow, 2008). This shows awareness in students of the importance of technology in the future, but an uncertainty of what is available in terms of STEM jobs.

Students and Technology

The survey of students in grades 3-12 showed that they are using digital resources outside of school for downloading and uploading videos, podcasts, and photos; playing online games; creating or modifying digital media; using MashUp sites; blogging; participating in 3D virtual worlds; sharing resources; or contributing to wikis (Project Tomorrow, 2008). This youth culture is engaging with digital technologies in their everyday life (Hsi, 2007). Multiple attempts have been made to label this new generation of tech-savvy users and their experiences growing up in the digital era. Prensky (2007) calls these students "digital natives," born during the time of digital technology, constantly surrounded by it, and growing up using it. Another term to describe those who are well-versed in technology is "digitally literate." Digital literacy can be looked at as "the skills, knowledge and understanding that enables critical, creative, discerning and safe practices when engaging with digital technologies in all areas of life" (Hague & Payton, 2010, p. 19). These digital technologies include, but are not limited to, mobile phones, websites such as social networking and online gaming, computers, email, music players, and authoring tools (Hague & Payton, 2010). Hsi (2007) looks at the practice of students interacting with digital technology as “digital fluency,” where students are voluntarily involved with technology, expressing themselves, and designing their own work while building skills and knowledge. Hsi (2007) maintains that these digitally fluent kids are working on complex problems, multitasking, taking on multiple roles and identities through their work, and are collaborating with others to construct a social reality and establishing and following norms of participation for these social realities. These experiences may or may not lead to learning about specific content matter, but the goal is about the meaningful activity for the user.

However, there must be caution when discussing this youthful generation’s knowledge about technology. Vaidhyanathan (2008) states that there is a common misconception that all youths are tech-savvy, given that there is a broad spectrum of what people can do with technology. Oblinger (2008) stresses that students come into the classroom with different levels of expertise and that, for example, students using a web browser does not equate to finding and learning from quality sources. Bennett, Maton, and Kervin (2008) found in their research that there is a lack of evidence to support the claim that there is “a homogenous generation with technical expertise and a distinctive learning style” that is based on this technical knowledge (p. 780). In other words, lumping all young people—whether called the Net Generation (Tapscott, 1998), Millenials (Howe & Strauss, 2003), or the Digital Generation—into one group of technologically advanced users is too simplistic. In fact, Herring (2008) maintains that all these labels are coined by adults, and the lens through which adults see new and advanced technology is simply normal to the youth population. While the interest in and use of technology may be prevalent among the youth, they still need opportunities to build real skill and knowledge.

Statement of the Problem

The youth culture has a natural affinity toward video games and research has shown that they have enthusiasm for taking part in the creation and design of video games, a good way to encourage their interest in technology. The United States needs to continue to encourage the K-12 students to become interested in technology and other STEM-related fields in order to remain competitive in the global economy which will be based on science and technology (Atkinson et al., 2007). Although it seems that the youth culture is already tech-savvy and knowledgeable about technology, there are various levels of understanding on how to work with technology. Additionally, there appears to be confusion about how this knowledge of technology could be related to future STEM careers.

Programs designated in video game design have shown promising results in encouragement, motivation, and interest in technology, as well as developing skills in problem solving and working collaboratively, which will be outlined further in Chapter 2. Games (2008) suggests that these types of skills represented in game design are similar to those identified as necessary for the 21st century. Thus, given the interest children already show for video games, the need to encourage them toward STEM-related fields and the push to encourage 21st century thinking, video game design seems the ideal platform to make these connections. In order to address the emphasis placed on the fields of technology and science for the global economy, this study looked at how a game design learning environment using science concepts may improve attitudes toward science and technology. In order to address the push for 21st century thinking, students were observed in the roles of learners-as-designers as they explored their science topics.

The problem of this study was to investigate the process by which students in this learning environment are able to understand unfamiliar science topics and how they portray this understanding of these topics through their video games. This study also aimed to discover if this experience improves student interest and confidence in their abilities about science and game design.

Research Questions

The overarching questions driving this study are:

RQ1: How do students create video games on science concepts about which they are unfamiliar?

RQ2: How does designing educational science games affect student attitudes toward science and video game design?

The following subquestions will be asked in this study:

RQ1a: What strategies do students as designers use in order to understand the science concepts?

RQ1b: How do students exhibit their understanding of the science concepts through their video games, the design process, and their explanation of these?

RQ2a: How does the game design experience affect student attitudes toward science?

RQ2b: How does the game design experience affect student attitudes toward making video games?

Research Goals

The goals of this research study were twofold. The first goal was to create a learning environment where middle and high school students were presented with unfamiliar science topics and provided the opportunity for learning, problem-solving, researching, collaborating, and creating an artifiact that embodies the science concepts in the context of video game design, skills that are representative of 21st century thinking. There have been a few studies that have integrated science content into video game design (Baytak, 2009; Kafai & Ching, 2001; Yarnall & Kafai, 1996). These studies all use science concepts that are integrated with the science lessons that students are learning in their classrooms. In my study, students worked with science concepts which were not part of a middle school or high school curriculum and were unfamiliar to them. Presenting students with an unfamiliar topic becomes a challenge that needs to be solved, as they must first learn about the science in order to create a game about it. This allows for a novel opportunity for students to learn and explore high-level topics while creating their games, effectively learning through design. It also allows all the students in the program to start from relatively the same starting point, with respect to prior knowledge about the topics. To scaffold them through this process, students worked with a science subject matter expert from the Federation of American Scientists, and were provided with a series of learner-supported tools. Through this learning environment, it was hoped that students would be able to develop their own strategies for finding ways to solve the problems of (a) understanding their science topic and (b) designing a game about this science topic. It was anticipated that these two components necessary for creating the game would cooperatively reveal to the students what they still needed to understand and work on. Their understanding of the science topics was monitored through student actions, discussions, reflections, and their final products, the video games.

Through this game design experience, it was hoped that the second goal of this research project would be attained, to stimulate students' interest in science and technology. As students learned about their topics in order to teach them through their games, it was hoped that their familarity with the topic would make them more confident in their abilities to learn about other science topics and perhaps carry this with them when considering classes and career paths. Additionally, as students may have come into the game workshop because they love video games, it was hoped they would use the skills and knowledge they learned about programming and designing games to further encourage them toward STEM-related fields.

The two goals of the study are based on qualitative and quantitative research questions, respectively. However, the quantitative research questions in this study did not attempt to make generalizable statistical inferences to a larger popultion. Rather, this study will serve to further inform on how the students may change their attitudes toward science and technology through experiencing this particular game design environment. This study was set up so that students were provided with learner support tools in order to explore an unfamiliar topic while creating their games, providing them with a platform to learn through design as they created their video games. As such, there was not a focus on assessing a quantitative gain in scientific knowledge from the students in this study. Papert's (1991) notion of constructionism, particularly with respect to the artifact as an external representation of knowledge, played a key role this decision. Papert emphasizes that the artifact is the outcome of the process students go through while interacting with their environment and shaping their internal knowledge structures. Because of this, I studied the design process while students created their artifacts (video games), as well as examined their final products, instead of concentrating on taking pre- and posttest measures to examine student understanding of their topics.

Significance of the Study

This study may be beneficial to educators in that it provides a framework for a learning environment where students can be interested, engaged, and involved in researching about new topics for the benefit of their own knowledge. This makes it beneficial to the students working in this environment as well, as they are given an opportunity to be both learner and teacher while working with technology. Lastly, this learning envirionment shows how we can expose and stimulate the interests of students in science and technology in order to help them as they prepare for their future careers in the global economy.

Definition of Terms

The following terms are used in specific ways in this study.

Video Games – In this study, the term is used to refer to any digital game, whether on a computer, platform, or device, such as an Xbox or an iPad. With reference to the video games that students produce, the games are created through game-design software and played on a computer.

Design Process – This is the process students go through from thinking of an idea, sketching out work on paper, programming the game, collaborating with peers and the scientist, and thinking about and interacting with the game, until a final product is achieved.

Game Maker – This is the game-design software used by students to create their game. It allows students to experience object-oriented programming through drag-and-drop features, using menus to select commands, and short coding scripts.

Programming – In this study, referring to students as "programming" refers to them using the Game Maker software for their work.

S-SME – The Science Subject Matter Expert, a scientist working at the Federation of American Scientists who meets with the students every week and guides them through their understanding of their science topics.

2. LITERATURE REVIEW

This chapter will delve into the relevant literature that supports this study's purpose to create a learning environment through video game design to help students construct their own knowledge about unfamiliar science constructs. The idea of students creating their own constructs of knowledge rests on the epistemology of constructivism, which will first be explored through the ideas of cognitive/genetic psychologist Jean Piaget, and social constructivist Lev Vygotsky. This will then lead to a discussion of constructivist learning environments and constructionism, which places the constructivist learner in the context of creating some kind of artifact. The founder of constructionism is Seymour Papert, who is also one of the pioneers of engaging children in active design, and the description of his work will introduce the idea of looking at children as designers, and then more specifically, as game designers. A review of the research done on children as game designers will be outlined, which will highlight the importance of allowing this population the opportunity for design. This will showcase the goals of this study and set the stage for the methodology of the study in Chapter 3.

Constructivism

Constructivism is an epistemology that emphasizes learning as an active process in which the learner takes responsibility for constructing his or her own knowledge. To understand constructivism, it is helpful to contrast it with another epistemology, objectivism, which emphasizes that learning is a passive process for the learner, who is judged to have acquired knowledge by giving the correct responses to specific stimuli. Looking at both viewpoints side by side captures the role of the learner; in objectivism, the learner *gets* knowledge, whereas in constructivism, the learner *creates* knowledge.

Piaget's Constructivism

Jean Piaget, whose ideas are associated with constructivist theory, began his own research on how learners create knowledge by observing children, specifically his own three children (Wadsworth, 1996). In watching them meticulously, Piaget became aware of a connection between early childhood actions and later cognitive development. Wadsworth (1996) says this time helped Piaget with his theory of cognitive development, which outlines the characteristics that children acquire and exhibit during four stages of their childhood based on their experiences. As the child progresses through each of these stages, he or she encounters and interacts with new information, and is able to process this information with a higher level of understanding (Piaget, 1972). At each stage, the child experiences three processes which are responsible for his or her cognitive development and eventual transition to the next stage: assimilation, accommodation, and equilibration. Assimilation is experienced when the child meets new information and must try to integrate it with his or her internal structures of knowledge that already exist, or through the way he or she currently views the world. Accommodation occurs as his or her existing structures of knowledge are adapted to include the new information, which may change the way he or she sees the world. Piaget saw the mind as a type of filing cabinet, where each file represents schema, or some kind of knowledge structure. The child uses the schemata to organize the world that is seen through his or her own experiences and reactions, and can constantly adapt or change the schemata to fit the world that is being viewed. However, there may be periods of conflicts, gaps, and contradiction between the new information coming in and what he or she already believes, called “disequilibration.” The resolution of these conflicts brings the child back to a stable equilibrium, which is a vital component of cognitive development, as it allows for the child to move toward more sophisticated thinking while constructing his or her own knowledge (Piaget, 1972). Through this work, the foundations of constructivist theory are evident: The learner constructs knowledge through experiences, using what is already known to help make sense of what is unfamiliar, sometimes needing to make room for something that does not fit.

Vygotsky’s Constructivism

Piaget’s views focuses on knowledge that is created from the reflective interaction of the individual and the individual’s experiences. Lev Vygotsky’s (1978) work on how children learn extends this notion, which emphasizes social and cultural relationships as influences on the individual’s knowledge construction. Starting from the birth, the child begins to interact with his or her social world through the tool of language, which is determined by the culture by which he or she is surrounded. At first, the words he or she learns are not connected to thoughts as the child verbally communicates in his or her environment, but as the child grows, he or she internally reflects on meanings and is able to form concepts and develop intellectually (Vygotsky, 1962). Vygotsky (1978) states that the child’s cultural development happens during two different periods: first, between people, which he calls interpsychological, and then within the child, or intrapsychological. It is in the intrapsychological experience where the child, now in the stage of adolescence, becomes reflective and conscious about his or her own thinking as he or she continues to interact with the environment.

The social interaction becomes more evident with Vygotsky’s (1978) theory of the zone of proximal development, or ZPD. The ZPD is the point to which a child can do or learn something with assistance, through the guided support of adults or with more developed peers. The ZPD is situated between a zone of actual development, which is what the child can do independently, and a zone of undeveloped capabilities, which is what the child cannot yet do (Driscoll, 2005). As the child is appropriately instructed and guided while in the ZPD, the zone boundaries can shift over into the undeveloped territory, highlighting an advance in development (Vygotsky, 1978). This supports the notion of scaffolding, a term used to describe when an instructor (or other type of advanced learner) supports the learner in the construction of knowledge (Driscoll, 2005). Scaffolding is used in many constructivist learning environments.

Piaget’s and Vygotsky’s theories present, on one hand, similar insights about the way that a learner internally constructs knowledge based on a type of experience in an external world. Yet, on the other hand, Bruner (1997) highlights the differences between their two theories in that Piaget presents a logical mind that constructs and organizes knowledge based on the individual’s interaction with the world, while Vygotsky presents a mind that is able to interpret and make meaning of what is going on in the world that is based on social interaction. Bruner (1997) claims that these two theories are incommensurable, but are not without their own truths.

Constructivist Learning Environments (CLEs)

Constructivism focuses on the learner, with the project or problem as the driving force of knowledge construction, and the instructor acting as a facilitator (Savery & Duffy, 1996). The instructor as facilitator does not mean that the learner does not receive instruction, but rather is guided with tools and environments that support active learning (Jonassen, 1991). Jonassen (1999) highlights a model for constructivist learning environments (CLEs):

1. Learner interprets a problem or completes a project.
2. Learner makes connections to related cases.
3. Learner is supported by information resources.
4. Learner uses cognitive tools to interpret and manipulate the problem/project.
5. Learner communicates with others through collaboration tools.
6. Learner is given social/contextual support.

The problem or project in a CLE is ill-defined or ill-structured to allow for the fact that there is no “right” or “wrong” solution, but instead leaves the door open to consider how viable the leaner’s knowledge or explanations are in relation to other alternatives (Duffy & Cunningham, 1996). Thomas (2000) further describes the role of the project in CLE environments in that it must include the five criteria of centrality, driving question, constructive investigations, autonomy, and realism. The project is central in that it is the entire point of the curriculum; the project is the way the learner answers the driving question of the curriculum; the project is an investigation in constructing new knowledge; the project is learner-driven and allows the learner to work on parts of it independently; the project should be less schoollike and more authentic and meaningful to the learner (Thomas, 2000). This outline of a project in a CLE fits well with Jonassen's (1999) model and would fit well in a technology-focused project.

To understand the problem or project, the learner needs a base of related experiences from which to refer (Jonassen, 1999). A type of constructivist pedagogy called cased-based reasoning maintains that learners build knowledge and experiences as cases in their minds, retrieving similar situations as a foundation for what may have worked or failed before, and allowing this new experience to become encoded as a new case (Kolodner, 1993; Kolodner et al., 2003). This also relates back to Piaget's (1972) notion of trying to fit in knowledge from new experiences into an existing organizational system in the mind, and if not, then restructuring the filing system.

To investigate or explore the problem/project, the learner needs rich sources of information to support learning, such as texts, graphics, videos, and websites (Jonassen, 1999). Of particular importance is the allowance for resources to be available for the learner to select for "just-in-time learning." This allows for information to be ready just when it needs to be explored or to help in completing some kind of process or activity.

In order for the learner to be able perform the tasks needed to solve the problem or complete the project, the tools available need to support the tasks, specifically in ways to support knowledge construction. This may include tools that allow for visual manipulation of the problem concepts, systems that allow for dynamic modeling, or even powerful search engines that facilitate in the knowledge-gathering process (Jonassen, 1999).

Likewise, there should be tools that allow for discussion and collaboration between the learner and the instructor, peers, and other community members. Recent technology advancements have moved from listservs, email, and discussion boards to blogs, wikis, virtual environments, and even multiuser video games as tools for collaboration (Guterman, 2008; Ketelhut, Clarke, Nelson, & Dukas, 2008; Spires, 2008). This distinction between cognitive tools and collaboration tools for knowledge construction may also be based in the distinction between Piaget's constructivism and Vygotsky's constructivism: In a CLE, there is the affordance for both types of experiences to come through.

Additionally, with respect to the social and cultural aspect of Vygotsky's ideas, the social context of the learning environment must be supported so that learners are not in some way offended or even disengaged from the project or problem they are investigating (Jonassen, 1999). This includes giving support to and training the teachers of this learning environment, so that they can better support the learners.

Constructionism

Seymour Papert worked with Jean Piaget in the late 1950s to early 1960s, who influenced him in understanding the process of learning (Papert, 1980). According to Papert (1980), when Piaget speaks of the development of the child, it cannot be separated from the development of knowledge. This led Papert, a mathematician, to the design of a tool that would aid children with developing their own knowledge. The tool was LOGO, a programming language for children, which included a Turtle object that children could control through LOGO commands (Papert et al., 1978). By programming instructions on the computer, sixth graders were able to have their Turtle—which first began with a physical robotic object on a piece of paper but later turned into a cursor on the computer screen—move by their specified directions to create simple geometric shapes to more complex figures. The children were taught the basic commands of LOGO and how to work in the programming environment, then were given reign to experiment and to define their own tasks (Papert et al., 1978). The first tasks would involve the children coming up with an object they wanted to create, such as a flower, writing out the steps on paper on how to create it, and then using the LOGO commands to create the flower through the computer. Papert et al. (1978) stated that the children began to have a sense of control and ownership over these designs. Some children continued to make simple designs while others wanted to move onto more complex ones. Yet even when the children needed help from a teacher, rather than the teacher giving them the programming instructions, they would discuss a heuristic method to help solve the problem. A child asking how to program the Turtle cursor to draw a circle would receive a description of how the child himself or herself might move in order to make a circle, and how to translate this into LOGO commands (Papert, 1980). This example shows its roots of constructivism: The role of the teacher is as facilitator and the child is not given an answer but rather given direction to build upon the internal knowledge structures that already exist in order to create new ones.

The work with LOGO laid the foundation for Papert to propose constructionism, a learning theory that takes the constructivist stance that learning is actively constructed within the mind of the learner, situated in the context of creation (Papert, 1991).

> Construction*n*ism—the N word as opposed to the V word—shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe. (Papert, 1991, p. 1)

Kafai and Resnick (1996) state that constructionism is the learning that develops from two types of construction: constructing knowledge while constructing some type of meaningful artifact. They further advocate that learners become "intellectually engaged" through constructionism by making connections with the knowledge they are gaining, through a learning environment that encourages different styles of learning and different representations of knowledge (Kafai & Resnick, 1996). Not only are the learners making these connections for themselves, but by producing an artifact through the learning experience, they have a physical object that can be seen by others. According to Papert (1991), it is the artifact that allows the learner to externalize the internal knowledge structures that are being shaped through interactions in the environment.

This Study

This study centered on a constructionist learning environment, with emphasis on learners engaged in creating an artifact—in this case, video games—and interacting with their learning environment as they build their artifacts to shape their understanding of science topics. It also drew upon Jonassen's (1999) model for constructivist learning principles to support the learner throughout the process. Papert (1980) states that constructionism takes the constructivist principles of learners constructing internal knowledge structures one step further by placing it in a context where learners construct knowledge through building artifacts. In this case, constructionism is no longer concerned with just the internal thoughts in the learner's mind, but on the knowledge that is being created through the artifact and the connection the learner makes to it. The video game was thus a key piece in understanding students' understanding of the science concepts on which the games were based.

The Computer in Constructionism

In the constructionist learning environment, the learner needs to be able to explore and engage in the creation process, which has led many constructionist research designs to utilize computers or computerlike technologies, such as instructional software (Harel, 1990), video games (Kafai, 1995), multimedia environments (Neo, Neo, & Kwok, 2012), programmable Legos and Legolike structures (Resnick, 2007) and robotics (Rusk, Resnick, Berg, & Pezalla-Granlund, 2008). Technology is an important vehicle for constructionism, as it offers a powerful and flexible working environment for learners to explore and learn on their own (Stager, 2001). Kordaki (2004) states that computers are ideal as a medium for constructivist learning because they allow students to be expressive, take control of their own learning, and provide instant visual feedback of their actions. Indeed, the origins of constructionism were developed from a computer programming language for children (Papert, 1980). Yet Falbel (1991) cautions about the way computers are used for learning, which still rings true almost two decades later. A computer program that asks the user to answer specific questions is not allowing the user to take control of a learning experience; however, a user who is using a programming language has the freedom to instruct the computer, instead of the other way around. Thus, the way that the computer is used in the constructionist learning environment is very important.

Learners as Designers

Harel’s (1988) seminal work on children designing instructional software had fourth graders using the computer to program in LOGO, specifically designed with Papert’s constructionist ideas in mind. Over a period of four months, 17 fourth-grade students were given lessons on software design, programming in LOGO, and fractions, but left to their own devices to create their own software that would teach fractions to other children. The students were found to be motivated to learn about mathematics through this process, to create real representations of math and put them to use in creating software, to make personal connections to their projects, to think about how to teach fractions through the software and thereby “teach through design,” and to integrate multiple aspects of curriculum, activity, imagination, and self-reflection into one project (Harel, 1990). The students were found to increase their understanding and knowledge of both fractions and the LOGO programming language, as well as to develop problem-finding, problem-solving, and reflection skills. This study exemplified constructionist theory as it engaged the students in an open-ended project that allowed them to build knowledge through their own software creations, and allowed the researchers to observe this process by following their activities around the design artifacts. Harel also credited Perkins' (1986) work in *Knowledge as Design* as an influence on the study, who argues that an environment for learning based on the creation of a design promotes the active use of knowledge by the learner (Harel & Papert, 1991). Indeed, this study highlighted the idea of "learners as designers." It inspired the next study in following child designers through looking at learners as video game designers.

Learners as Game Designers

Kafai's (1995) doctoral dissertation in 1993 reexamined and extended Harel's (1988) work and turned it into a video game design project. The design setup was similar: Sixteen fourth-grade students were given an ill-defined task to design educational games teaching fractions to other children through LOGO. This study observed students' design styles as they created their games over a period of six months and how their ideas developed over time. Some created a plan in the beginning and followed it through to the end; others changed their designs as they came to interact with the programming language and understand the concepts of fractions. The students were also immersed in a learning culture where they shared a common task but approached it in different ways, yet were still able to discuss with one another, help each other design games, and play each other's games (Kafai, 1995). These observations also emphasized Kafai's (1995) findings that designing games offers a powerful way to stimulate learning.

Kafai (1995) used the slightly different context of designing video games in acknowledgement of the enthusiasm children already felt for the technology, moving from consumers to producers. This change was reflected in the way the students in each study thought about and designed their games. Students in Harel’s (1988) study brought the concept of using fractions to the foreground of the instructional software that was created whereas students in Kafai’s (1995) study put the concept of fractions in the background. For example, most artifacts in the instructional software project focused on a type of tutorial in instructing the user about fractions, whereas most of the games focused on a type of playful context where the user confronted different situations and had to solve a fraction in order to move on in the game (Kafai, 1995). The representations of the fractions in the software artifacts used more interesting ideas, such as using a fractions clock or representations with money. The games, although using more generic representations of fractions such as dividing a shape into sections, relied on a narrative and required more complex programming as the stories in the game adapted to the interactions of the users solving the fraction problems.

The issue of separating the content from the games was addressed in a later study by Kafai, Franke, Ching, and Shih (1998). During discussions with fifth-grade students designing games about fractions, the authors gave a challenge to the students to create games that do not ask questions, such as quiz games. This need was derived from past experience with students designing games, as many student ideas had centered around quizzes and stopping game play to ask a question (Kafai, 1995; Kafai, Ching, & Marshall, 1997). The authors found that this helped reshape the way students created their games and they were able to evaluate the games based on how much integration there was between the fractions content and the game design, the types of fractions represented in the game, and the type of thinking that went into making the game. The authors also applied the findings from this student session, called the conceptual design tools, to a session where teachers created games about fractions (Kafai et al., 1998).

These studies by Harel (1990) and Kafai (e.g., 1995) were exemplary with the ideas of children making artifacts and learning through design. They opened doors for thinking about new ways to place children in design-centered approaches for learning, especially in video game design. For my study in particular, these works served as the foundation of my game design learning environment. The basic premise of providing an opportunity for students to create their own games and observing their process is very powerful, and as Harel and Kafai have demonstrated, it allows a glimpse into the inner thinking of the students as they learn through video game design.

Game Design Research

Hayes and Games (2008) claim there are four main avenues of research in making video games in educational settings: (a) helping students learn programming concepts, (b) attracting students—especially females and other underrepresented populations—toward technical fields such as computer science, (c) enhancing the understanding of an academic domain, and (d) facilitating learning of making games or features of games. The authors note that learning programming concepts are prevalent in the other three categories as well. Games (2009) offers further detail on these categories in his doctoral dissertation. While these categories highlight the purposes for which game design environments have been created, they do not offer immediate insight into the resources, tools, and guidance students were offered in support of their game creation. I first present a review of the literature within the context of Jonassen’s (1999) model of a constructivist learning environment, with respect to the games driving the design process, the resources and tools provided for individual learner support, the opportunities for learners to make connections and to collaborate, and the social and contextual support. This further informed my study of a learner-supported game design environment while continuing to respect the categories presented by Hayes and Games (2008). Because of the constructionist nature of the game design environments, this literature is ideal for examining under the lens of a constructivist learning environment.

Game Design CLEs

Learner completes a project (game). Students in a game-making environment have a goal to create some kind of game or elements of a game. This may include creating a game with a programming language (Harel, 1990; Kafai, 1995), using game-making toolkits that utilize programming concepts but require little knowledge of programming code (Baytak, 2009; Click, 2014; Kafai & Peppler, 2012; Werner, Campe, & Denner, 2012), modifying existing games or game-like environments (Bruckman, 1997; Hayes & King, 2009; Robertson & Good, 2006), or by putting together multimedia elements (Neo et al., 2012). Although many of these game creation tools also allow for the creation of storytelling movies and narratives in a similar fashion as creating games (e.g., Kelleher & Pausch, 2006; Szafron et al., 2005), this study adhered to the definition of games which designate an element of interaction. Robertson and Howells (2008) make the point that a game that responds to user input requires the game creator to include a “specification of conditions, consequences and sequences of behavior, which is not required in writing text, or producing still or moving images" (p. 563). Of particular note were the studies of Harel (1990) and Kafai et al. (Kafai & Ching, 2001; Kafai et al., 1997) that include children designing instructional software, which also fits this definition.

As a result of the different tools used to create the games, the artifacts that are described in the research vary greatly. The games produced from the studies that began the game design research were based in the late 1980s to early 1990s, and so the pixilated images and poor animations are very dated with the advancements of technology (Harel, 1990; Kafai, 1995). Games that are modified from existing game engines will still have the "look" of the original game as users are able to utilize their characters and richly designed environments (Hayes & King, 2009; Robertson & Good, 2005). Many tools used for game design allow students to create their own images and scenery for their games, and these games will differ in play as the designers need to create the goals of the game from start to finish. Some studies admit this becomes a daunting task and the students are unable to finish, especially due to time constraints (Robertson & Howells, 2008). Interestingly, there is a lack of description in the literature of how long it takes to play the finished games, from start to finish.

The topics of the games described in the literature also vary. For those games derived from design environments that concentrate on an academic domain, the games' focuses include mathematics (Harel, 1990; Kafai, 1995), science (Baytak, Land, & Smith, 2011; Ioannidou, Repenning, Lewis, Cherry, & Rader, 2003; Kafai & Ching, 2001), history (Ioannidou et al., 2003), literacy (Owston, Wideman, Ronda, & Brown, 2009;

Robertson & Howells, 2008; Robertson, 2012), engineering (Blanchfield, 2009; Coller & Scott, 2009) and design skills (Games, 2010; Kafai & Peppler, 2012). Studies also use games that are created in environments aimed to encourage interest in computer science but do not have a specific academic focus (Click, 2014; Denner & Werner, 2007; Flannagan, Howe, & Nissenbaum, 2005, Werner et al., 2012).

Additionally, the games varied within each study as well, which is to be expected in open-ended design environments. In Baytak’s (2009) dissertation study of fifth-grade students designing environmental science games in the classroom, the games included topics of pollution, global warming, and overpopulation. The representation of these topics also varied; one student’s game centered on an oil spill, while another student’s solution to overpopulation was to send his characters to Mars. Baytak (2009) mentions that the teacher of the classroom assessed these games by looking at the information that was portrayed on a case-by-case basis. Of the student who created a game about the oil spill, the teacher noted that the facts were correctly portrayed in that the oil would keep spreading if not cleaned up and that this would cause additional effects, such as harming sea life.

Game assessment of the artifacts produced in these studies varies according to context of the study. The open-ended nature of these environments allows students to use various design strategies and produces a multitude of different responses based on those strategies (Robertson & Nicholson, 2007). Additionally, the emphasis on these artifacts is not to produce a “right” or “wrong” answer, but is based more on an architectural design of creating good solutions rather than bad ones (Kafai & Ching, 2001). However, some design programs find the need to look at the games produced as part of the entire representation of the experience. For game design environments that stress the importance of learning programming concepts, some studies look at the technical aspects included across all the games (Baytak, 2009) while others look at the content of screens created (Kafai et al., 1997). Robertson (2012) rated games created by students to tell stories based on eight dimensions, including visual design, dialogue, and imagination. Kafai and Peppler (2012) considered the assessment of games created by the same authors over a period time based on the categories of originality of idea, criticality, use of medium, technique, and overall skill. The game themes created by students in Robertson's (2012) and Kafai and Peppler's (2012) studies were created based on their own choosing, while the games in the study of Baytak (2009) and Kafai et al. (1997) were specifically created with an academic focus; thus the goals of assessing the games are different for each study based on the parameters the students are given to create them.

Assessing knowledge learned from creating the games is also a method of evaluation. Harel (1990) and Kafai (1995) found that students increased their knowledge about fractions and programming through their design environments; Kafai et al. (1997) found that students increased their knowledge about astronomy concepts and fractions; Baytak (2009) found that students did not have any significant increase in their knowledge about environmental science after making their games.

Regardless of *what* types of games have been produced and their assessment, all the game design environments put particular emphasis on *how* these games were produced. In describing this process, they reveal the ways students were supported in their design process.

Learner makes connections to related cases. Giving students in a learning environment different perspectives or examples of what type of project they are considering allows them to enhance their understanding. Especially relevant to child designers is to give them a type of case to compare the current project or problem to, with the notion that they as a designer will construct their own interpretations of it (Jonassen, 1999). Some studies do this by presenting example games (Baytak, 2009) or by providing sample scenarios to complete before tackling a project on their own (Denner & Werner, 2005). Other studies do this through discussion of related examples, such as thinking about fractions and linking them to examples in the real world (Harel, 1990; Kafai, 1995; Kafai et al., 1998).

Kafai and Ching (2001) created a study for students to design instructional science software based on neuroscience concepts. Prior to going to into the game design environment, students were taken to a laboratory and were able to dissect a sheep's eye and also listen to a surgeon talk about the differences between a sheep's brain and a human brain. Although not expressly described in the study, it can be inferred that these activities were meant to be used as cases to which the students could refer once they began to design their artifacts.

Learner is supported by information resources. Across the literature of the game design environments, the students are learning some type of new skill in programming and or introduced to a new piece of software to construct games. In learning how to use the tools alone, they will require some guidance. Most of these game and programming environments are commercially available and have a rich user-supported community online. Hayes and Games (2008) comment on the support system for the game design software Game Maker, which includes wikis, blogs, and message boards where the user community offers helpful advice to designers working with this software. *The Game Maker's Apprentice* is a companion text that provides insight on design and thinking about rules, characters, and the mechanics of the games created in that environment (Habgood & Overmars, 2006). Scratch, another game design toolkit, (n.d.) also provides tutorials, a forum for users for advice and support, as well as a gallery for sharing projects and a day set aside each year for users to come together to discuss and share their Scratch projects. Hayes and King (2009) discuss the fan sites and the user community surrounding versions of the game *The Sims* and its role in encouraging users to use available tools to modify the game to create their own game scenarios. As they followed their study of women modifying *The Sims 2* to create their own game, they found that their participants used the online tutorials to help them create the games and used the fan sites for feedback and encouragement (Hayes, King, & Lammers, 2008).

Game design environments with a specific focus on an academic domain would have a different need of information resources. In addition to the students learning the technical aspects of game design, there is an additional focus on content. Baytak's (2009; Baytak et al., 2011) studies focused on students creating environmental issue games, and the students had discussions with teachers about their topics. In Harel's (1990) and Kafai's (1995) work on students creating artifacts about fractions, fourth-grade students discussed issues about fractions in Focus Sessions to enhance their understanding about fractions. These studies did not provide any additional information resources that students could access on their own. Kafai and Ching’s (2001) students designed instructional software based on neuroscience and were informed of websites with additional information which they could explore on their own, as well as class discussions and laboratory experiments.

Learner uses cognitive tools. Many of the software tools used in the game design environments were created to specifically provide performance support to the users. As briefly mentioned earlier, Game Maker and Scratch are game design software that allow students to build games with little to no knowledge of a programming language. Without having to learn an entire programming language in order produce games, students can immediately focus on the design aspects and see results of their work quickly. Game Maker and Scratch both use drag-and-drop actions to create the commands that will be used with the game, a process that emphasizes basic programming concepts. For example, in Game Maker, users assign a Sprite (graphical image) to an Object (character) in the game and then drag-and-drop icons that represent an Event (e.g., a keystroke) to trigger an Action (e.g., jump) that the Object will take (Habgood & Overmars, 2006). In this sense, the user is modeling what the programming language would do. Modeling provides a way for taking formal representations of knowledge and representing them in ways that make them more understandable to the learner (Jonassen, 1999). A significant feature of Game Maker in particular is that users can see the code that is generated from their drag-and-drop actions and can also switch to writing their games in the programming language code once they have mastered the concepts.

A particularly interesting way of modeling the design of games is done through the software tool Gamestar Mechanic (Games, 2010). This tool is actually a game alongside game design software, which scaffolds the users into thinking about designing games through performing small tasks which they can later apply to making their own games. The user plays the tasks by editing a game that is missing a key feature in order to be playable, such as a maze that has no clear path to a goal. The user becomes the mechanic in this sense to fix the game, or in this case, clear the path for the game character to reach the end of the maze. These kinds of tasks introduce users to working with the software to create their own games, but also gives them a sense of the mechanics of games themselves and what makes them playable and interesting. The game environment of Gamestar Mechanic also uses icons and drag-and-drop actions to create the games, but unlike Game Maker, does not provide opportunities to program with code.

Another tool that is prevalent in the game design literature is not so much a physical tool as a way of representing the process of game design. Some studies have identified that establishing an iterative process of game design is helpful to guide students through making games (Click, 2014; Resnick, 2007; Robertson & Nicholson, 2007). The iterative process more or less includes stages for reflection, design, testing, and discussion. Along with the discussion time, the testing period also includes other members of the game design environment, whether instructors, peers, or even the entire class.

Reflection. The period of reflection is one where students are able to think about what they want to design. Robertson and Nicholson (2007) call this time “idea generation” while Resnick (2007) simplifies it to “imagine.” From the studies of Harel (1990) and Kafai (1995), students were given “Designer Notebooks” to prompt the reflection process. Each day that was spent working on their designs, students spent some time at the beginning writing about what they wanted to do and spent some time at the end writing about what had been done and any problems that were encountered. Kafai (1995) noted that this helped students to document their progress and reflect on their thoughts and ideas and could be used as a rich data source. Additional studies in game design have added this feature to their learning environments (Baytak, 2009; Denner & Werner, 2007; Robertson & Nicholson, 2007), and this idea is also used in design environments that are not based on making games (Kolodner et al., 2003). Kolodner et al. (2003) in particular used the notebooks for students to think through science concepts, which would make this kind of tool ideal for game design environments with a focus on a specific academic domain.

Design. This is the time period of construction of the games. Resnick (2007) refers to this as the time to “create” while Robertson and Nicholson (2007) separate it into “design” and “implementation,” marking a particular time between reflection and construction to determine the specific design elements of the game. This may include periods of reflection as well, especially as students refer back to their Designer Notebooks.

Testing. This is a period of testing out the games to see how they work, akin to "game testing" by Robertson and Nicholson (2007) and "play" by Resnick (2007). Robertson and Nicholson (2007) note that the design period also includes periods of testing and redesign as the students are trying out the ideas for themselves. This may include the notion of "debugging," which in computer science relates to the notion of finding errors in the code and fixing them. This may also include the notion of "tinkering," which can involve testing out features of the software to see what it can do (Hayes & King, 2009). Resnick and Rosenbaum (2013) maintain that tinkering is an important step in exploring ideas and experimenting with possibilities. Testing may occur by the game designer, by another student, or in front of the class as a presentation. This kind of testing elicits feedback from others that the designer will be able to use.

Discussion. This is the period where other people in the design learning environments offer opinions and advice on the students' games. The designer must then consider how to utilize this feedback in the game. This aligns with what Robertson and Nicholson (2007) describe as "evaluation" and links with Resnick's (2007) ideas of "share" and "reflect." In some learning environments, younger students were brought in to play the games that were created and to offer feedback to the creators (Baytak, 2009; Harel, 1988; Kafai, 1995). Others involved other game designers from the class playing the games and offering advice (Denner & Werner, 2007; Games, 2010). One study involved posting games to a public forum for feedback (Hayes et al., 2008). The feedback that the game designers receive from those who play their game can give them new perspectives about what is missing from the game, or what should be taken away. The feedback from player to designer and the subsequent utilization of that feedback by the designer into the game is what Games (2010) calls a dialog between player and designer. This kind of back-and-forth is also found during professional game design (Salen & Zimmerman, 2006).

This kind of process is iterative, because after receiving feedback, the game designer may want to go back to the game and change it. This leads to another cycle of the reflect-design-test-discuss process. The lines between these stages blur and do not necessarily need to be completed in order, as designers go back to the stages as needed as their games progress (Robertson & Nicholson, 2007). Other studies have adopted similar types of iterative processes, more akin to the software design world and rapid prototyping (Flannagan et al., 2005).

Learner communicates with others through collaboration tools. Collaboration is a key aspect of many game design learning environments. Some studies discuss having game designers come together during group sessions so they can all share ideas (Baytak, 2009; Harel, 1990; Kafai, 1995; Kafai & Ching, 2001). This is in line with Brown's (1994) community of learners, where students come together to share knowledge about a common learning interest.

Denner and Werner (2007) setup their all-girls program so that everyone worked in pairs, sharing roles of driver and navigator. The girls had to get used to working together and sharing a computer, so the authors set up scenarios where the navigator read aloud instructions so the driver could perform them (Denner, Werner, Bean & Campe, 2005). This helped the girls understand how to work together and many of them came to enjoy having partners. The authors report that, in pairs, the girls were effective at reminding each other to use resources and to compare a problem to an instance that was already working.

Sheridan et al.’s (2009) study of middle and high school students working in a game design studio (of which I was a graduate research assistant) integrated a peer mentoring model where experienced game design students helped newer students entering the program to scaffold their learning experience. Kafai and Ching (2001) also incorporated a similar mentoring model. Additionally, Sheridan et al. (2009) found that the new students in the program, sitting next to each other in the computer lab, would watch each other’s computers and comment on each other’s work, often asking the question “How did you do that?” The students in this design studio naturally collaborated with each through helping each other with their projects.

Learner is given social/contextual support. Social, cultural, and contextual factors of the game design learning environment can impact the way that students work in the environment. Social and cultural considerations can include creating all-female environments (Denner & Werner, 2007; Flannagan et al., 2005) and environments for underrepresented populations (Sheridan et al., 2009). Scott, Clark, Sheridan, Hayes, and Mruczek (2010) refer to these environments as Culturally Relevant Computing Programs, where the implementations of these environments take consideration for the needs of the participants and the teachers who work closely with them.

Flannagan et al. (2005) created a program for females, primarily from disadvantaged homes, to encourage their interests toward computer science. They used a program called RAPUNSEL which allowed the girls to program dancer figures and take care of these dancers through a nurturing structure such as *NeoPets*. The authors found that they had to restructure some of the values of their program. For instance, the nurturing care structure they hoped would be implemented turned into a more competitive structure, so a new rewards system was built into the program. Also, the original focus was for the girls to strictly program their games to foster programming skills, but the girls wanted more instant feedback of their games, especially through modifying existing games. Thus, the authors took this into consideration and incorporated this aspect into the program, along with a feature where the girls could share their own code with other participants. This switched the original focus of the program from learning how to program to learning "how to create a compelling environment in which programming is a central element" (Flannagan et al., 2005, p. 754). These authors took in the considerations of their participants in order to make the learning environment work for them.

The contextual support in game design learning environments is also quite important. For example, teachers whose classrooms are taking part in these types of learning environments may require some type of professional development, either in the content that will be taught or even the game design environments themselves (Baytak, 2009). The students also need some contextual support, whether it be learning how to work with a partner through exercises (Denner & Werner, 2007) or time to explore the game design software (Robertson & Howells, 2008).

The Current Game Design Learning Environment

These elements of constructivist learning environments are prevalent in the literature with respect to game design, unsurprising as the environments all incorporate open-ended learning where students are free to express themselves through the creation of games. The literature reviewed describes game design environments through the context of learning support that is offered to the students in these environments, whether the learning is centered on programming and designing games, either within or without an academic domain. While the studies incorporate many of the learner-supported elements of a constructivist learning environment, it is not clear that any one study include all of these elements. What is clear is that none of these studies created their design environments with the express purpose of including these learner-supported elements. This current study situated the game design environment firmly within the constructivist learning model as outlined by Jonassen (1999) in order to provide learner-supported tools for game design. This works especially well for a game design model based on Papert’s (1980) theory of constructionism, where learners create artifacts that express their inner ideas. Thus, this study provided constructivist learning resources to help learners construct their own meaning and a game design model for learners to create artifacts expressing this knowledge. This allowed the study to (a) observe how participants construct their own meaning through creating games in a learner-supported environment, both through scaffolding and on their own, and (b) observe the games that are created, as an external expression of the meaning students have constructed.

Additionally, the game designers in the current study's learning environment were focused on creating games based on science concepts from immunology. These concepts were presented by a science subject matter expert from the Federation of American Scientists who worked on the FAS-created educational science video game Immune Attack (FAS, 2007), which is a game that teaches immunology concepts. The expert worked closely with the students throughout the entire game design learning environment, an element not found among the current game design environment literature. Bringing in a scientist who is connected to a video game adds an element of authenticity to the game design environment for the students' learning experience.

The last aspect of this current game design environment was to encourage students toward science and technology. One reason for having students work with science concepts in the context of video game design was to encourage their interest in the field. As such, this study looked to see if student attitudes toward science were affected based on their experiences in the game design environment. To date, this had not been looked at by any current game design learning environment.

Science and Game Design

Kafai and Ching (2001) conducted a study with fifth graders where they created instructional software about science concepts surrounding neuroscience. The authors make the point that their study brings in an alternative approach to students engaging in a practice of science by giving them a learning-through-design experience where they are creating architectural models of science, in contrast to engineering models of science. The difference is that an engineering model of science provides immediate feedback about the design (e.g. Kolodner et al., 2003), whereas an architectural model is not concerned with a “right” or “wrong” answer, but rather considers a good or bad solution. Kafai and Ching (2001) maintain that this “design approach to science inquiry promotes students’ ability to express their ideas and interests while integrating them within a science context” (p. 326). This study concentrated on looking at the science discourse that arose between the students as they collaborated on their instructional software designs. The authors refer to this as “science talk” and monitor the group interactions as they specifically refer to the science concepts during the design process. They found that this kind of science discourse does occur within the context of design, specifically during the planning stage and when discussing the actual design screens. Kafai and Ching (2001) found that including older peers who have already gone through a science design environment allowed for the conversations to be steered in a more fruitful direction. However, across seven teams, it was found that three teams did not engage in scientific discourse during the recorded group sessions, and focused more on design issues.

What Kafai and Ching (2001) have shown here is that science content can be integrated into a design activity that is meaningful to the students. Students in this type of setting have issues of design to deal with as well as issues of understanding the science concept, but the findings were positive in integrating them together in their games.

Science and Game Design in My Study

My study shared some similarities with Kafai and Ching (2001) in that it was a learning-through-design environment where students were asked to integrate science concepts into their design of an artifact. Where Kafai and Ching focused on if science discourse was occurring in relation to making the games, I looked more specifically at the science understanding students are able to represent in their games. Simultaneously, I examined how students utilized the information resources and tools provided for them as they created their games. Lastly, I hoped to discover if this experience of working with science through video games affected student attitudes toward science in an effort to encourage their interest in the field.

Summary

Game design learning environments are emerging as a way to engage students in meaningful activity while helping them learn about various disciplines or encourage their interest in a specific domain. New advancements in technology have offered many software tools that can scaffold users into creating games without the explicit need to write code, which allows them to get feedback from their work instantly and produce games more quickly. As such, students are creating video games on their own, in pairs, or with groups, either from the ground up, templates, or by modifying existing games.

The literature described here shows that student designers in these learning environments are supported through a variety of methods to enhance their design process and use of academic content in their games. These supportive tools include using the creation of games to drive the learning experience; providing information resources, tools, and collaboration opportunities to aid designers in their knowledge construction; and taking into consideration the social and contextual needs of the participants.

Game design has been seen as an avenue to help attract students toward computer science fields. The encouragement of students in the fields of science, technology, engineering, and mathematics is becoming one of national initiative. As of yet, it is not clear whether game design with a concentration of science content can be an avenue for interest in science.

My study purposively selected these elements of a learner-supported game design environment where students were focused on creating educational science games. They were supported with constructivist learning resources as they were emerged in a constructionist environment to create meaningful artifacts that express their ideas. This study examined how students utilized these resources as they began to understand the science concepts upon which their games were based and how the games reflected their understanding. Students worked closely with a science expert from the Federation of American Scientists. It was hoped that this design experience would advance student interest in STEM fields.

3. METHODS

This chapter describes the methodology that is used to conduct a mixed methods study. First, this chapter will present a rationale for using mixed methods in acquiring and analyzing the data collected. Next, the research questions of this study will be reintroduced. This will be followed by a description of the research setting, participants, materials, data collection, data analysis, and validity issues.

Research Design

A mixed methods research design allows for both qualitative and quantitative data collection procedures and analysis to be combined into one research study in order to understand the research problem (Creswell, 2008). The argument for a mixed methods research design is that combining both quantitative and qualitative methods will provide a more complete look at the research problem than any one single method, especially as each method has its own limitations (Creswell, 2008; Greene, 2007). Reichardt and Cook (1979) maintain that mixing methods allows for the most appropriate methods to be used in the research design. Greene (2007) discusses it as not only mixing the processes, but combining the various approaches of research at multiple levels, such as methodology, philosophy, theory, and values, and acknowledging that there are multiple and diverse forms of knowledge. According to Greene (2007), mixing methods becomes a way of thinking which engages a dialogue between this diversity in order to gain a better understanding of the social inquiry at hand.

The mixed methods research design used in this study followed Maxwell and Loomis's (2003) outline for an integrated mixed methods research design. This approach looks at the components of a research study, including the purpose, conceptual framework, research questions, methods, and strategies for checking validity, and considers how they work together and influence one another. In each component of the study, the quantitative and qualitative approaches are delineated, yet examined under the original umbrella of integration. There was an emphasis of qualitative work in this study on how students created science-based video games; the quantitative portion involved assessing student attitudes toward science and video games. Yet the two sections are related and were aligned to set up an opportunity for dialogue between the two approaches in each component of the study (Greene, 2007).

Both qualitative and quantitative approaches were used in this study, to be further outlined later in this chapter, in order to answer the following research questions which were the overarching questions driving this study:

RQ1: How do students create video games on science concepts about which they are unfamiliar?

RQ2: How does designing educational science games affect student attitudes toward science and video game design?

The following subquestions will be asked in this study:

RQ1a: What strategies do students as designers use in order to understand the science concepts?

RQ1b: How do students exhibit their understanding of the science concepts through their video games, the design process, and their explanation of these?

RQ2a: How does the game design experience affect student attitudes toward science?

RQ2b: How does the game design experience affect student attitudes toward making video games?

Research Setting

Overview of Design Workshop

Students participated in a 3.5-week-long game design workshop that met every weekday. The day lasted for approximately six hours, with an hour break for lunch and socialization. They collaborated with the science subject matter expert (S-SME) who presented them with science concepts based on immunology. Students were given Game Design Journals at the start of the workshop, available to them if they wanted to take notes or sketch out ideas. The concepts were presented as four categories and students selected the category that interested them the most, thereby creating four groups based on similar topic choices. Fourteen of the 16 students selected their own topics; two students indicated they did not have a preference and each were placed in a category that only had 3 members. This created four groups with four members each. Students were then asked to design a video game to portray their understanding of the science topic. The S-SME met with each group once a week to help them understand their topics, as a resource for information. Of the four meetings with the S-SME, the first consisted of an introductury lecture to the entire group of students, followed by three more meetings with invididual groups, lasting from 30 minutes to an hour. In addition to meetings on science topics, video game instructors gave presentations on how to work with the game design software throughout each week. Peer mentors were on hand to help the students on the technical aspects of their video games. Thus, students were immersed in a learning environment which involved science learning and video game learning simultaneously. Although the majority of students in this design workshop were already familiar with the software being used, they were tasked with creating new aspects of their game that fit in with their specific science topic. At the end of the 3.5-week workshop, students had a workable artifact to be presented to the class and an audience of parents, which involved explaining both the science concept and the technical aspect of their video games.

Overview of CLE Design Principles

The students in this study were immersed in a constructivist learning environment (CLE). As Jonassen (1999) outlines six elements for a CLE, these elements were incorporated into the game design workshop for the students.

1) *Learner interprets the problem/ completes the project*. Students were presented four science topics and asked to select one as the focus of their video game. They were given the opportunity to interpret how to create the game about their science topic on their own.

2) *Learner makes connections to related cases.* Students were shown demos of the publicly available science video game, Immune Attack, where a nanobot character goes inside the human body to explore, learn, and carry out tasks. Programming instructors also showed sample video games (not about science) that were created using the same platform the students would use. In this way, students were given an opportunity to see both a video game about science as well as a video game created from start to finish on their software platform, in an effort to have them think about their own game—in effect, a hybrid of these two cases.

3) *Learner is supported by information resources*. Students were first given access to the most important information resource of all: the science expert. Meetings with the science expert provided an interactive information resource, with discussions guided by the students. In addition to this, references were provided for the students to do research on their own. Students were also surrounded by instructors and peer mentors, who were valuable sources of information for programming issues and game design feedback.

4) *Learner uses cognitive tools to interpret and manipulate the problem/project*. A cognitive tool is one that allows students to visually see and manipulate the problem. In this way, the game-making platform Game Maker was an excellent tool for students to create a visual game about the science topic.

5) *Learner communicates with others through collaboration tools*. As a tool, a website was created for students to discuss ideas and share images. In the

learning environment, students were within close proximity to each other and could easily collaborate as well. Students were also grouped according to the science topic they chose and were provided opportunities for discussion.

6) *Learner is given social/contextual support*. Students were provided with peer mentors to help with the technical aspects of designing a game. These mentors were close in age with the students and had gone through the program before, allowing for a peer-to-peer relationship when asking for help, rather than instructor-to-student.

Site

The research site used for this study was a branch campus at a large Mid-Atlantic university, making use of a computer lab, a lecture room, and a private conference room. There were 24 student personal computers (PCs) in the lab, as well as one instructor PC located at the head of the room. The instructor PC's monitor was projected onto a board facing all 24 student computers. The computer lab was where students worked on their games and listened to technical lectures by the computer instructors. The lecture room was used for meetings with the S-SME. The private conference room was used for individual meetings between the students and the researcher of this study. Students arrived to the campus via public transportation on their own or were dropped off by a parent or guardian.

Participants

Students.

Sixteen students participated in this study, 14 boys and 2 girls, within the age range 12 to 16 years, from both middle school and high school. There were 15

African American students and 1 Caucasian student. All indicated that they had computers at home with Internet connection and played video games regularly. Only three students had not used the game-making platform Game Maker prior to this study. Any names used to refer to the participants in this study have been changed to keep them anonymous.

Many of the participants of this study had been involved in a previous research study focusing on a video game design workshop where they learned aspects of game design through a peer-mentoring system (Clark & Sheridan, 2010; Sheridan et al., 2009). The workshop was designed to increase motivation and awareness of STEM fields and careers, as well as increase skill and knowledge in computer animation, programming, and design through a peer-mentoring system. The original sessions took place at a technology-based urban high school and were held on Saturdays for two hours in two 10-week sessions throughout the school year. A condensed version of this program was held during the summer for a small amount of students in order to focus on mentor training and leadership.

Recruitment for this summer session was based on reaching out to the students and parents of the students involved in the previous 10-week spring session. Potential participants were informed that they would be able to continue learning about video game design during the summer, but that there would be a new focus on creating educational science games and collaborating with a science expert from Federation of American Scientists. Ten of the 16 students participating in this study had previously participated in the spring session of the program.

Peer mentors. Eight male peer mentors helped students with technical and programming issues in the workshop, ages ranging from 15 to 20. Peer mentors were students that had previously been involved in the game design workshop or had experience with the software used in the workshop and had a mastery of the concepts that are being taught. The peer mentoring model was added to the original research study for two main purposes: (a) to allow students to feel comfortable in asking questions about their work from students close to their own age, and (b) to allow students who fell behind or wanted to advance their work to receive one-on-one instruction while the instructors of the game workshop classes continued their lessons without interruption (Clark & Sheridan, 2010; Sheridan et al., 2009; Sheridan et al., 2013).

The peer mentors were not expected to—and were in fact encouraged not to—help the students with designing their science games or explaining the science concepts to them. This is because (a) the peer mentors were not expected to have any knowledge of these science concepts introduced to the participants, and (b) the focus of this study was for the students to understand the science concepts through their own means and design the games based on their own understanding. However, the mentors did help students by playing games and providing feedback, which included science-related questions.

Instructors. There were three college-aged instructors on hand during the workshop, two male and one female. All three instructors were proficient in programming with the Game Maker software and led the students through an introductuctory/review lesson of the software, as well as specific lessons including adding multiple levels to the game, creating a starting page and ending credits, and building the documentation features of the game (i.e. “help”). One instructor was also proficient in Adobe Illustrator and led a lesson on creating sprites from scratch, as well as how to incorporate premade images found online.

Science Subject Matter Expert (S-SME). The subject matter expert was a scientist with a Ph.D. in biology, working with the Federation of American Scientists on incorporating technology with science learning. She had been the science coordinator for the educational science game Immune Attack (http://immuneattack.org), a game that allows students to explore immunology. Her experience as the subject matter expert for Immune Attack allowed her to lend her expertise with incorporating science into the students’ own video games. The S-SME also took part in the preliminary trial study of students creating their own science games, which this research study is based on (Khalili, Sheridan, Williams, Clark, & Stegman, 2011).

Researcher. As the researcher of the project, my role required both my interaction and silent observation. My interactions included setting up the classroom every day; talking with the S-SME, instructors, and peer mentors about the day’s structure and lessons throughout the day; and also conversing with the students. Although I tried to limit my conversations with the students as they were actively working on their projects, they all knew me and were comfortable to talk to me about topics relating outside of the classroom, as well as their projects, mostly at the start and end of the day. Once the day’s lessons and sessions working on their games started in the computer lab, however, I took the role of silent observation as much as could be allowed, walking around the room and taking down my observations of the class with field notes and video and audiorecording of conversations. At the end of each week, I did make a point to stop by every student's workstation and ask them direct questions about their game and their progress in a type of informal interview, where I then recorded their responses to me with an audiorecorder as they explained their game. In the lecture room meetings, I videorecorded the interactions between the S-SME and students and stood beside the camera, so my presence was almost always unobserved, with the attention of the students focused solely on the S-SME. During one-on-one semistructured interviews with the students, we would be seated in a private conference room, where I would ask questions and listen to the students while audiorecording the conversation and taking down notes.

Technology Tools

Game design software. The game design software used in this study was Game Maker (http://www.yoyogames.com/gamemaker/), which is available as a free download. This software allows for the students to learn basic concepts of object-oriented programming without the need to write explicit code in a computer programming language. Object-oriented programming focuses on creating "objects" that perform certain actions. An object in real life is something like a dog, a chair, a car. Likewise, in a video game, an object could be a character in the game. In Game Maker, an object is associated with a sprite, which is the graphical representation of the character on the screen. An action that a character might perform in a game could be "moving across the screen." In Game Maker, actions are triggered by events. An event could be something like pressing a key on the computer. Game Maker breaks down the creation of a game into these categories of Objects, Sprites, Events, and Actions so that the user can, for example, think about what kind of character is needed in the game (Object), find an image to assign to that object (Sprite), decide that pressing the “up arrow” on the screen will cause the character to jump (Event), and have the action associated with pressing the “up arrow” make the sprite on the game screen move upwards (Action). Assigning Sprites, Events, and Actions to an Object are all done through icons in a drag-and-drop fashion so that very little needs to be written in terms of code, although users have the option to see the code that is generated by their decisions. Game Maker allows users to create video games more quickly than the time it would take to learn a programming language and then create a game using that lanuage. The users are still being exposed to basic programming concepts and are required to think about the relationships between Objects, Sprites, Events, and Actions in a video game, but with faster results.

Image editing. Students were also given two minilessons on Adobe Illustrator by one of the instructors who was proficient with this software. Students were shown how to import, edit, create, and export images that they could later incorporate into their video games. Students were also found using the software Paint in order to create or edit images on their own.

Website. An online forum was created specifically for the design workshop where students could message each other, upload pictures and links, and access websites and videos that the S-SME had uploaded for student use. Due to the close proximity of students in the computer lab, the messaging system was for the most part neglected, with students instead opting to ask questions in person and gather around each other’s computers to learn from each other. This was also the usual way to show each other images and links that they had found useful or interesting. The website was mainly used for the list of links that the S-SME had provided of approved science websites, as well as for the video of the lecture that the S-SME had given when introducing the four science concepts, which had been recorded and uploaded the following day. This was especially useful for the two students who had missed the first days of the program.

Data Collection

Data collection took place over the 3.5 weeks of the design workshop. This included the students' Game Design Journals, observations, student pre- and post-surveys, student interviews, final student presentations, as well as the final games that were created.

Table 1 shows how each of these data collection methods relates to the research questions being asked.

Game Design Journals

Each student participant was given a folder with sheets available for notetaking and storyboarding, designated as a Game Design Journal to be used throughout the course of the workshop. This was a feature in Harel's (1988) and Kafai's (1995) work with students creating video games with LOGO, which was found to be helpful to the students in terms of thinking through their ideas, and also helpful to the researcher in collecting student data and observing the progression of their ideas. Journals were handed out at the start of each day and collected at the end of the day. Students were not required to take notes, nor were they given any specific prompts to write about in their journals; rather, the journals were available for students to use as needed. It was observed that the journals were primarily used for both notetaking and storyboarding, with the majority of the notes taken during the introductory class lecture given by the S-SME. All students used the storyboarding sheets to attempt to draw either an idea of the game they wanted to make, or to draw representations of the images they wanted to include in their games.

Surveys

Pre-survey. The students were given a pre-survey (see Appendix A) at the start of the game design workshop. There were four parts to this survey. The first part asked general background information, as well as questions about technology proficiency and interest in school subjects and potential career choices. The second part included questions about attitudes about science. The third part included questions about attitudes about making video games. The fourth part included five questions that asked students to look at science diagrams. Students were asked to take parts I and II on the first day of the workshop and parts III and IV and the second day of the workshop.

The science attitudes instrument a modified version of the TOSRA: Test of Science-Related Attitudes (Fraser, 1981). The original 70-item instrument was created to measure science-related attitudes among secondary school students through seven subscales, three of which are used in this study: Adoption of Scientific Attitudes (10 items), Enjoyment of Science Lessons (10 items), and Career Interest in Science (10 items). This instrument has been used in separate studies using all of the subscales as well as selected subscales (Fraser, 1979; Fisher & Fraser, 1980). The author of instrument has shown the internal reliability of the scale using Cronbach’s alpha to be .75, .78 and .84 for the respective subscales used in this study (Fraser, 1981). The author further notes that this scale could be used for pre- and post-surveys to observe changes in science attitudes, which was the intent of the current study.

The video game design instrument is based on the Intrinsic Motivational Inquiry instrument (Deci, Eghrari, Patrick, & Leone, 1994). It was created to be used in assessing participants’ experience related to a targeted activity, in this case designing video games. The original version is a 45-item instrument with seven subscales; in this study, three scales were used. The subscales used in this study were interest/enjoyment (five items), perceived competence (four items), and value/usefulness (three items). The authors of the IMI have stated that past research suggests that the inclusion or exclusions of the subscales do not have an impact on each other. A separate group of researchers did a study on the IMI and found strong support for its validity (McAuley, Duncan, & Tammen, 1989).

The five multiple-choice questions of the survey were created by the S-SME and asked students to look at a given science diagram and answer the question “I would be able to understand this diagram if I read it and thought about it” by answering on a 5-point scale from 1 “I disagree definitely” to 3 “I am neutral” to 5 “I agree definitely.” These questions had been selected by the S-SME from her own instrument used when polling students after playing the game Immune Attack.

Post-surveys. Students were given a post-survey during the last week of the game design workshop. There were four parts to this survey. The first part asked information about completing the video game, the resources that were used to learn about the science topic, and what they enjoyed and disliked about making their game. Parts II, III, and IV were identical to the pre-survey, asking the same questions about attitudes in science, attitudes in making games, and the five questions about science diagrams provided by the S-SME. This was done in order to detect any changes in attitudes toward science and video games based on the students' experience with the design workshop. The first two parts were given on the second to last day of the last week, while the last two parts were given on the last day.

Interviews

Informal interviews. Informal interviews took place throughout the course of the workshop at the end of each week, between the researcher and a student. They occurred one-on-one at the end of every week, at the student's own computer workstation. The researcher would make a point to stop by at everyone's station and ask a question such as "Tell me about your game" to allow the students a chance to discuss, in their own words, their progress. These types of interviews were unstructured and often led by the students, depending on what they wanted to point out in their game. These interviews were also recorded by an audiorecorder so the researcher could concentrate on looking at the students' screens as they were often playing their game while explaining it. These short interviews took anywhere from one to three minutes, depending on how much the student wanted to discuss. They provided insight on the progress of the games throughout each week.

Semistructured interviews. Ten students were selected for longer semistructured interviews (see Appendix B). Initially, two students from each group were selected for the interviews, to get a representation from all topics. Group-4 was racing at the last minute to finish their game for the final presentation, so only one member from that team was able to be pulled away for an interview. As time allowed and games were finished up before the presentation, three additional students were added to the inverview schedule. Interviews lasted from 7 to 15 minutes, depending on the length of the students' responses.

Observations

Classroom observation. In the computer lab, I would walk around the lab and watch the students working on their games, taking notes on each group of students that would come together and discuss their games, either together or with a peer mentor or instructor. Sometimes I would be able to listen and write notes on a notepad, other times I would be able to stand closer to the group and audiorecord their conversations. At the end of the day, once the students had gone home, I would be able to translate my handwritten notes to a computer file. The audio recordings were also transcribed by me to the computer, although these transcriptions would take longer to transcribe than the end of the day.

It was important to be able write down my own reflections of the day before the next day's session started, in order to retain the information (Glesne, 2005). I kept a separate notebook where I would jot down thoughts, obervations, and general ideas of the workshop at the end of the day.

S-SME group observation. Students met with the S-SME once a week. These sessions were recorded with video camera, as meetings were held in a private conference room and no more than four students at a time were present at a session, making it easy to capture a conversation. Sessions were later transcribed by me to a computer file.

Video Games

Game. The artifacts the students created were not only a representation of what they had been able to learn and create, but also a data source. The progress of games were noted through observation notes, videorecorded descriptions of the games to the S-SME, and audiorecorded miniinterviews at the end of each week of students describing their games to the researcher. Thus, by the end of the game design workshop, the evolution of the game could be followed from the first idea to its iterations of change to the final product.

Presentation of the game. On the final day of the workshop, parents were invited along with the students to watch the final presentations of the games. Students played their games on a projected screen to the audience, explaining the science concept used in the game while doing so. Some additional questions were asked by the audience members as well. The presentations by the students and their answers to the questions were videorecorded (and later transcribed by the researcher) in order to use as a data source.

Table 1

Connection of Research Questions to Data Collection Methods

Research Question	Methods	Data Type
RQ1a: What methods do students use in order to understand the science concepts?	Observations Game Design Journals Interviews Video Games Surveys	Qualitative Quantitative
RQ1b: How do students portray their understanding of the science concepts through their video games?	Observations Game Design Journals Interviews Video Games	Qualitative
RQ2a: How does the video game design experience affect student attitudes toward science?	Surveys Interviews	Quantitative Qualitative
RQ2b: How does the video game design experience affect student attitudes toward designing video games?	Surveys Interviews	Quantitative Qualitative

Data Analysis

Qualitative

Miles and Huberman (1994) write that in qualitative analysis, the researcher will "review a set of fieldnotes [sic], transcribed or synthesized, and…dissect them meaningfully while keeping the relations between the parts intact" (p. 56). The data to be reviewed in this study came in the form of field notes, transcripts of weekly student check-ins, transcripts of meetings between the S-SME and the groups, transcripts of student interviews, and transcripts of the final student presentations. (The Game Design

Journals, video games, and transcripts of the final student presentations would also be analyzed with the S-SME, described in the next section.) I uploaded these files to be coded with the qualitative analysis software tool NVivo, but I also created a binder of all the files, divided into two sections. The first section contained field notes and all the transcripts in chronological order for each week; this is the section I used for this part of the analysis.

I began the analysis, as Corbin and Strauss (2008) suggest, with a first read: going through all the data, line by line, without taking notes. Then, going back through, reading line by line and assigning codes through open coding. I found it easier to read the files in the first section of my binder while having the computerized file on the screen and assigning the codes (or nodes) through the software tool.

As I coded, I also took memos (Corbin & Strauss, 2008; Maxwell, 2005; Miles & Huberman, 1994). Writing memos allowed me to reflect upon the data I was analyzing and provided me the opportunity to ask questions or to jot down connections I was beginning to see forming. In this way, I was able to write down all my thoughts about particular codes, find connections, and understand what needed further exploration.

Asking questions from the data is a part of how codes become revealed. My research question of *How do students create video games on science concepts about which they are unfamiliar?* was broken down as I asked questions of my data such as *How are students making their games? What strategies are being used? How do students understand their topic? How are they talking about science? How are students putting science in the game?* These are some of the questions that guided me as my codes were developed. However, preestablished categories were not used during reading; codes were identified based on what came out of the data.

Coding involved multiple reviews of the data and many revisions of the code. Redundant codes would be eliminated and as this was done, themes would emerge. I would constantly go back to the data, using the themes as the headings to collect my data together with NVivo. From there, I would then concentrate on finding patterns and making connections by going back through the notes with more focused coding. Creswell (2008) refers to this as discriminant sampling, purposely looking for evidence and events to support the questions and categories (themes) that emerge. Maxwell (2005) points out a distinction between coding (as a categorizing strategy) and connecting strategies. He states that “connecting analysis attempts to understand the data…in context, using varying methods to identify the relationships among the different elements of the text” (p. 98).

Here is where memos helped tremendously, in order to find the connections. For instance, one code that started out as “Science Talk” later broke away into another code of “Science Discussion,” where longer and more science-focused conversations were taking place. This was always happening with the S-SME, which later proved to show had an impact on student games changing. In order to make these connections, the student games were also studied as well to study the changes made. Then, another round of reading through the data revealed that the discussions with the S-SME started with the students, from questions they brought in, to questions they did not know they had until they started talking about their games. Thus, memos helped formulate my thoughts, ask the questions, and guide me through this chain of evidence within my data, in order to make theoretical connections.

Video game analysis. The artifacts were analyzed as to how well the students were able to convey their understanding of science through their games. This was based on a ranking system that was developed after examining all the games and the final presentations, with the aid of the S-SME. All the games were first examined side-by-side to establish the range of understanding of the science concepts portrayed in the games. Yarnall and Kafai (1996), in their study of students making games on oceanography, also looked across all the completed games to develop categories of rich, moderate, and minimal with regards to the science content incorporation in the games.

Three distinct classifications of games emerged when both the researcher and the S-SME evaluated games separately: High, Medium, and Low. Games were rated based on (a) accuracy of the science content as explained by the students, and (b) the portrayal of the science topic in the game in itself. For accuracy of the science topic, we looked to see if the students used correct vocabulary and were able to explain their topic well. For the portrayal of the game concept, we looked to see how the students showed their understanding of the concept as a video game, stylized in their own interpretation. For example, it did not matter that a skull image was used to represent a virus in the game, what mattered is if it made sense for a virus to be present in the game. Kafai and Ching (2001) note this as the artistic process of game design, rather than architectural. Students were placed in the High group if they could clearly define and explain their concept while playing their game, and if the game correctly interpreted the science concept. Students were placed in the Medium group if they showed they had a good grasp of understanding their topic but had made minor mistakes in their game and/or explanation (for example, using the wrong name even though they had the right concept). Students were placed in the Low group if they had key problems in explaining the concept and the game, for example interchanging viruses and bacteria and not understanding the difference. Baytak (2009) similarly created an outline for teachers to grade environmental science games for the students, assessing science content with four levels for scientific value and richness. As with Yarnall and Kafai (1997), these rankings were established through the clear distinctions of level of among the games.

Quantitative

The pre- and post-survey were analyzed using paired *t*-test statistical analysis to determine the mean differences between the science attitudes pre- to posttest, as well as the mean differences between video game attitudes pre- to posttest. This was done using SPSS.

For science attitudes, there were two sections to be analyzed on the surveys. One section consisted of the modified TOSRA: Test of Science-Related Attitudes (Fraser, 1981) questions. The other section consisted of five science diagrams created by the Science Subject Matter Expert.

For video game attitudes, there were also two sections to be analyzed on the surveys. One section consisted of the modified Intrinsic Motivational Inquiry instrument (Deci et al., 1994). The other section consisted of a series of questions which asked if students enjoyed making games about various subjects, including Science, Mathematics, English, and History.

Validity Issues

According to Maxwell (2005), validity refers to “the correctness or credibility of a description, conclusion, explanation, interpretation, or other sort of account” (p. 106). Validity concerns are with the inferences made during the study, whether it is what is written in the field notes or during the data analysis. The researcher needs to identify specific threats to the validity of the study and attempt to develop methods to rule them out (Maxwell, 2005).

With this in mind, before I began the study, I thought about the strategies I could use to help test the validity of my study and my conclusions. It was important to give thought to this before starting the study in order to be aware of what I needed to do in my data collection and analysis.

Third party coding. As my study is focused on observing the process by which students develop strategies to understand science concepts for creating video games, one of the biggest validity threats is that my interpretations drawn from the data are not accurate with regard to what the students are doing, creating, and saying. To address this threat, I enlisted the help of a third party coder to examine the data I had analyzed. This third party coder received approximately 30% of the raw data along with my codebook in order to code the data on her own. She coded the data separately and had highlighted many of the same student strategies as the researcher. She did not find anything new in the data that differed from the researcher.

Science subject matter expertise. A big part of my study is to look at the understanding of the science concepts by the students. As my research background is not in science, it was necessary to bring in another perspective in reviewing the data to ensure my interpretations of the science interactions are accurate. The Science Subject Matter Expert (S-SME) assisted in reviewing the video games produced by the students. She was present throughout the completion of the video games, and thoroughly reviewed each video game and the transcripts of the final presentations at the end of the study. The S-SME was able to give feedback on the science content present within the games and how well the students themselves were able to explain the science concepts they had studied.

Drawing upon the source of the science expert to interpret this data and develop meaning from it is similar to what Fish (1980) refers to as using an interpretive community, which is a group that shares strategies and influences the shape of what is being read and interpreted instead of relying on textbook-based definitions. With the help of the S-SME, I was able to get scientific interpretations from her, shaped by her own scientific community that is rooted in an educational video game environment.

Student responses. In order to gather data on student progress and their own explanations of their video games, I interviewed students though weekly check-ins and, for some, during slightly longer interviews. With this task, I was especially interested in the students' own words about their progress. A threat to the validity of the student responses would be if I asked a leading question to get a desired result. However, because I was working with middle school and high school students (and have done so in the past), I realized the necessity of prompting them to talk about their work. With this in mind, I followed a specific protocol. The start of each check-in began with a prompt such as “Tell me about your game.” The students would usually tell me about their game, but if I needed more detail or explanation, I would follow up with questions such as “What does this do?” or “Can you tell me more about this?” to specific points that were highlighted in their game. Many students also played their games during their explanations, so it was an ideal opportunity to gain more insight about what was going on in the game.

Since students were playing their games as they talked during the weekly check-ins, and because I wanted to concentrate on their games while also getting down exactly what they were saying, I used an audiorecorder when standing next to the students at their computers. Maxwell (2005) points out that in order to collect detailed and rich data to test the validity of your conclusions, verbatim transcripts of interviews are required. Thus, all interviews with students were audiorecorded and then transcribed verbatim; in addition, all meetings with the S-SME where students discussed their games and the final presentations were students discussed their games were videorecorded and then transcribed verbatim.

During the longer interviews, I used a template to guide my questions to the students, but I also used the opportunity to check in with the students on points that I had noticed from their work during the workshop. For instance, one of the strategies that I noticed that was being used was that students were creating their games based on games that they had already played, so I made sure to ask them about their inspiration for the games. In this way, I was able to get some feedback from the students themselves on a conclusion that was being formulated, as respondent validation (Miles & Huberman, 1994). Maxwell (2005) points out that this is a way to add more evidence to support the validity of any conclusions that are made.

Triangulation. Maxwell (2005) states that triangulation is a strategy for validity testing. Triangulation is the collection of information from different data sources and methods to gain a better perspective on the explanations that are being developed (Fielding & Fielding, 1986). I used multiple data sources to gain an understanding of student strategies as they developed their video games, including my own observations in the classroom and in group settings, interviews, surveys, and the video games themselves. For instance, to gain an understanding of how students portray their understanding of science concepts through their video games, I looked at the video games during different points during the workshop and also at the completion of the project. Yet, I also wanted to get the student perspective on what they believe is going on in their games, so I also gained their perspective during weekly informal interviews. Additionally, I asked the S-SME to lend her expert opinion on how she watched the students work through their understanding of the science concepts. Student explanations and the S-SME's expert opinion in conjunction with my own observations allowed for multiple sources on how I interpreted student understanding of the science concepts developing throughout the project.

Simply incorporating triangulation, however, does not increase the validity of the findings, especially since all of the sources of data are examined by the same researcher. I incorporated a triangulation of different data sources in order to help me look at the same idea from different perspectives. Yet, because I am the one asking questions from the students and I am looking at all these data sources from my own perspective, there is still a validity threat on the bias of my own reports. This is why it was also necessary for me to follow a protocol for asking interview questions, to solicit feedback from the students, to bring in a third party coder, and to gain insight from the perspective of the science expert, in order to help strengthen the validity of the findings.

Researcher bias. I designed this study because I am passionate about exposing students to science and technology fields in order to build their confidence and their attitudes toward these fields. I have worked on previous projects as a graduate research assistant where I observed students creating their own games and have analyzed results and made conclusions. Naturally this experience and my hope to encourage students in STEM fields is ingrained within me. However, I designed the study to allow the students to work in the learning environment without my influence and as the prime researcher of this study, I could not allow any bias to get in the way of collecting the data or analyzing the data. Before I conducted this study, I took effort to be especially aware of how I observed students: I could not only make note of situations where I noticed "learning" and positive situations of progress. I did this by specifically making note of this in my proposal: Having this awareness was the first step in trying to minimize the bias. Also, from my work as a research assistant, I have gotten into the habit of looking over my notes soon after the day has ended, transcribing handwritten notes to the computer, and adding things I may not have been able to add while on-the-go. This was the time where I would make sure that I was not only making notes of, for instance, the positive situations in the classroom and also including all parts of the learning environment, even where students were bored, stuck, confused, or uninterested in the project. Maxwell (2005) refers to this as actively searching for discrepant evidence and negative cases, and considers this as a check for validity. And indeed, along with the validity checks I made sure to incorporate throughout the data collection and analysis, these serve to help minimize the bias.

There are also aspects of my bias which I believe benefitted my study. My work as a graduate research assistant for three years (Clark & Sheridan, 2010; Sheridan et al., 2009) has helped me with observations and taking field notes, and helped me to be able to view the scenes before me with as objective a lens as possible for someone who is involved in the work. My background in computer science allowed me to appreciate the technical skills that the students developed and to understand the issues they faced when designing their games. My interest in using video games as a tool for learning motivated this research study. These beliefs and expectations that I carry with me influenced my project, yet they also helped carry it forward. Greene (2007) would say that these are mental models that shape my perceptual lens as a researcher.

4. FINDINGS

The purpose of this research study was to create a game design environment where students would be able to design their own video games based on an unfamiliar science topic, and provide them with the support and tools necessary to express their understanding of the topic through their games. The following research questions guided this study:

RQ1. How do students create video games on science concepts about which they are unfamiliar?

RQ2. How does designing science games affect student attitudes toward science and video game design?

More specifically,

RQ1a. What strategies do students as designers use in order to understand the science concepts?

RQ1b. How do students exhibit their understanding of the science concepts through their video games, the design process, and their explanation of these?

RQ2a. How does the game design experience affect student attitudes toward science?

RQ2b. How does the game design experience affect student attitudes toward making video games?

In this chapter, the findings of this study are presented for each research question.

Findings

The findings that emerged from this study are sorted into categories based on the research questions. Thus, the following categories are presented: (a) strategies students used to create video games, (b) student understanding of the science topic, and (c) Student attitudes toward science and making video games.

Strategies Students Used to Create Video Games on an Unfamiliar Science Topic

Finding 1: Students create science video games based on games they know.

Students were asked to create video games with a game design software with which they were familiar (or if they were not, a refresher course was offered in the beginning of the workshop). Many students had prototype games up and running by the second week of the workshop. It became clear that even if students were still coming to terms with understanding their science topic, they had no issues coming up with ideas on how the actual game would play out. When asked about their initial decisions on making their games, students had this to say:

> Noah: Well, I kinda looked through the old games that I’ve done. Like one of the old Pac-Man games I did. I liked the way that was setup. So I went off the structure that it was, like the mazes and stuff.

Joseph: Well, when [the scientist] was here, I kinda automatically took an idea of what I wanted to do, and also I related it to other games I played. And how, yeah, it’s like a search and find game, and those are the games I like.

Wanda: Well, in class, [the instructor] did an example, like Space Invaders. So I couldn’t really think of any other game that I could do.

David: I know you haven’t even played or seen the game, but there’s this game called Bioshock, Dead Space, and those types of game play elements I’m going to use into my game. And there’s this other cartoon called Osmosis Jones and Osmosis Jones has a friend named Drix, which is a pill that was taken into the body, ’cause like the whole story line is there are a bunch of cells fighting a bunch of germs in this body, and the body is supposed to be portrayed like New York or whatever cause it’s a big old city, and I figured since this environment is going to take place in the brain that it’s going to have a feel like it’s a pill fighting all these different things and holding off and protecting the brain while it’s going through the process of regulating genes.

Of the 12 final games that were presented, 11 of them were based on these well-known concepts of video games. The last game was based on a YouTube video that described DNA signal transduction, and the group that created their game modeled it after the video. The student, David, who originally intended to base his video game on the TV show Osmosis Jones and games like Bioshock, ended up designing his final game after an online/app game called Bejeweled. Table 2 outlines the type of games after which their own games were modeled, and their science translation.

Table 2

Game Genres Used and Their Science Translation

Student/Group	Topic	Game Genre (Specific Game)	Science Translation
Anthony	Gene Regulation	Third-person shooter	Shooting enemy bacteria
David	Gene Regulation/ DNA	Tile-based (Bejeweled)	Matching up nucleotides
Noah	Gene Regulation	Maze (Pac-Man)	Traversing a maze, collecting (turning on) colored genes
Wanda	Gene Regulation/ STD	Third-person shooter (Space Invaders)	Shooting diseases
Cameron	Myelin Sheath	Platform, Trivia	Traversing a maze, collecting proteins, answering a quiz
James	Myelin Sheath	Third-person shooter	Shooting enemy bacteria, collecting cells
Group-2	Myelin Sheath	Platform game (Princess Peach and Dinosaurs)	Characters jumping through levels to collect cells
Ethan	Neurotransmitters	Ball-and-Paddle (Pong)	Preventing enemy drugs from getting through
Michael	Neurotransmitters	First-person shooter	Clicking on enemies to make them disappear, to keep neurotransmitter levels balanced
Lawrence	Neurotransmitters	Third-person shooter	Shooting through barriers to release neurotransmitters
Scott	Neurotransmitters	Ball-and-paddle	Paddling the neurotransmitters into the receptors
Group-4	Signal the DNA	Puzzle (YouTube video)	Finding the right protein sequence

Consistent with this finding, Yarnall and Kafai (1996) found that their students modeled their electronic games about the ocean after commercial games and other media sources, such as television. In Kafai et al.’s (1998) study about video game designs in relation to gender, she also found that students were making games based on commercial games. Robertson and Nicholson (2007) also found that students used games and films as a source of inspiration for their games. Students needed a familiar starting point for creating their own games.

The video game genre used most often was Shooter (five games), followed by Maze (one), Ball-and-Paddle (two), Tiled-Based (one), Puzzle (one), and Platform (two). One of the Maze games also had an element of the Trivia genre as well. These video game genres are well-known and have been classified by a Wikipedia page on Video game genres (Video Game Genres, 2012). Hamlen (2011) also used the 2009 version of this page when classifying video game genres for her study on children’s game-playing strategies, finding it valuable because the information had originated from gamers.

Three of the Shooter-styled games had characters that shot at enemies. In all of these games, the main character was a nanobot, a miniscule robot that was a game feature found in the science game Immune Attack (which the students were shown at the start of the workshop) to explain how one could traverse through the human body in a game. These students—Anthony, James, and Wanda—also borrowed this feature and used the nanobot to “shoot” antibiotics at “enemy” bacteria or diseases.

Not all of the games were modeled in such an obvious fashion; Michael also designed his game in the style of a first-person Shooter game (where the main character is not on the screen) but rather than “shooting” at enemies, the player clicks on icons symbolizing adverse effects for neurotransmitters to eliminate them. Scott created a game where his nanobot character came into contact with bouncing neurotransmitters in order to push them toward the receptors. This is similar to a Ball-and-Paddle game, where the paddle guides the ball where it needs to go.

The students modified the game design of games that they were familiar with in order to incorporate their science content. This is not unlike the concept of game modding. Modding (where mod stands for modification) allows game designers to take the code of existing games and modify it to create a new game; many game creators even set up toolkits with their games so users can modify the games without having to do much programming. The benefits of modding include the shorter time it takes to create a game from scratch, a game that has already gone through testing, and a preestablished community of followers with which to discuss the game modifications; it also opens up a new world for learning with games (Hayes & King, 2009; Kringiel, 2011). In their study of students creating video games about nutrition, Baytak and Land (2010) found that one student modified an existing race car game to teach kids about nutrition. Instead of the racing car in the game, he substituted it with a cookie and had it chase after a person; if the cookie touched the person, the game was over. This scenario is very similar to how students created their video games, with one exception: Students did not take any existing code and modify it. They took an existing game design idea and modified it. The games were created on their own through the Game Maker software. It can be said that instead of game modding, students were *game design modding*. By modding a game design, students were quickly able to have an initial prototype for their science game, which allowed them to enter discussions with the S-SME more quickly as well.

Finding 2: Students gather information about unfamiliar science topics through Game Design Journals, web searches, and discussions with a science expert. Students were provided with multiple tools and resources to help them understand their science topic, including Game Design Journals for notetaking and drawing sketches and a website where students could email each other and the S-SME, videos, and a list of resources provided by the S-SME on the website, as well as access to the S-SME herself through weekly meetings. Table 3 shows a list of what students said was most helpful in designing their games in their post-surveys.

Table 3

What Students Said Was Most Helpful in Designing Their Games in Their Post-Surveys

	Notes	Diagrams	Email	Videos	Provided Links	Web Searches	Talking to Peers
Students	14	6	3	4	2	14	11
Percentage	87.5	37.5	18.8	25	12.5	87.5	68.8

Note. *N* = 16.

During the first days of the workshop, students were given Game Design Journals to help them write down ideas and sketch out game designs, similar to Harel (1990) and Kafai (1995). On the first day that the S-SME met with the students, she gave a presentation on four distinct topics that could be included in their game designs. Fourteen of the 16 students in the program took notes in their journals on that day, many of them referring and adding to these notes throughout the workshop. The two students who were not there for the presentation that day were able to watch a video of the presentation the following day and also took notes in their journals. Nine of the 12 students/groups drew sketches and outlined their game design in their journals, prior to beginning work on their games on the computer. The Game Design Journals provided a way for students to think about their topics and their games before starting programming and worrying about technical issues. It allowed students to reflect upon what incorporating a science topic into a video game would mean. Giving the students the Game Design Journals and time to write down ideas and sketches was a way to effectively prompt their reflection process. Davis (2003) notes that prompting for reflection can help students focus on their own thinking (metacognition) or on the content (sense-making).

As the game design workshop progressed, students had their journals with them every day at their computer stations, where they could access them if they wanted to write down a new piece of information or a question, and they carried the journals to every meeting with the S-SME. From observations of student use and the indication from Table 2, the notes in the Game Design Journals helped students when trying to formulate ideas about their science topics for their games. Appendices C and D show a sample of student notes and sketches from the Game Design Journals.

On the student website, the S-SME provided a list of trusted scientific websites, such as PubMed Central (http://www.ncbi.nlm.nih.gov/pmc/), 3dChem (http://www.3dchem.com/), and the Immune Attack website (http://immuneattack.org/). These websites were to be resources for students on the days when the S-SME was not available, as she visited once each week. However, the websites had articles that proved to be too complicated to read for students who are just starting out learning about these topics. Many students started out using the links on the website, but did not refer to them again when on their own in the computer lab.

At the beginning of the game design workshop, the S-SME led a discussion about the use of Wikipedia (http://www.wikipedia.org/). As a first stop to gain information about an unknown topic, Wikipedia would be accepted. Because it could explain difficult concepts in easier terms, the S-SME said it would be a good place to pick up key words and phrases. However, she cautioned that because anyone could edit the content of Wikipedia's pages, it could not be used as the only trusted source. The next step would be to gather the terms and information garnered by Wikipedia and search for them in trusted sites like PubMed Central. Kolodner et al. (2003) note that it is important for coaches or teachers to have a discussion with students about the resources that will be used for their projects to make sure they can be used successfully.

For the most part, students seemed to understand that Wikipedia was not to be used as their only trusted source.

James: I've heard some stuff about Wikipedia, that it's not always right.

Wanda: Not with Wikipedia, because I know that people can edit it.

Anthony: Is Wikipedia a reliable source?

S-SME: No. For a reliable source, you need to know an author and a publisher. On Wikipedia, you don't know the author. You can look through and find it, but you don't know the author, really. And the other thing, the publisher

> needs to be a respected source. So Wikipedia is a kind of publisher, but they tell you right away, we don't censor it. Anyone could put up anything—there is no criteria.

However, there were some students who admitted to using Wikipedia and other methods such as a Google search as their only research sources.

Researcher: How did you come across your information?

Nick: Wikipedia.

Researcher: Was this the only site you used?

Nick: Yes.

Researcher: Did you think that the information you were finding was accurate?

Nick: I didn't see why anyone would just go to Wikipedia and put lies up.

As the interview continues, it was revealed that Nick talked to the S-SME about all of his discoveries and the data on his work showed that he did indeed speak with the scientist during discussion meetings about what he found on Wikipedia. Looking through further data revealed that even if students were guided toward more reputable websites, they became uncomfortable in the unfamiliar vocabulary and higher level of language when reading on their own. What emerged instead was that students would check websites like Wikipedia for the information they were looking for and then bring their queries to the S-SME during their meetings. The scientist would then help them search through the articles on the trusted websites together.

In one such incident, the S-SME met with Nick and his partner Joseph, who decided to work together to make a game about the myelin sheath (referred to collectively as Group-2). At their first meeting together, they asked about why the myelin is coming off of the axon and pulled up the Wikipedia page they used during research. After reading about multiple sclerosis as type of demyelization disease, the S-SME suggested they use the keywords they pulled from Wikipedia and look for a trusted journal article about it. Both students searched on their respective computers and Joseph called their attention to one he found.

S-SME: Springer is the publisher…*Springer Seminars in Immunopathology* is the name of the journal, it says up here. It's the year 1996, volume 18, number 51. And the author is Brocke. Yeah, so this is not going to be very easy to read, but we can still try. "The Role of Infection in Multiple Sclerosis"—hey, excellent, excellent article! [All three laugh.]

The S-SME and Nick walked over to read the same article on Joseph's computer.

S-SME: Does it mention any pathogens?

Joseph: Talks about T-cells…

S-SME: T-cells…

Nick: Aren't those the same things as white blood cells?

S-SME: Yes, they are. They're a certain kind of white blood cell. They're the ones that tend to kill things. Maybe you could scan the whole article for the name o f a pathogen or bacteria.

At this point, they found that the article only showed a preview of the entire article and they could no longer access the full journal. The S-SME then suggested that they take information from what the article did offer them—the author's name, his lab and the keywords they found—to go to the author's website and gain more information.

S-SME: There it is—current research interests. He says he's researching the autoimmune part. Let's stay on this page. Hmm…he's got tools for stopping the white blood cells from getting there and killing the myelin.

Nick: I was thinking we might want to go with the autoimmune disease thing.

S-SME: Yeah, even if you want to go with pathogens, it will go back to autoimmune. And I think these guys have a way of blocking the antibodies. I think I can try to draw an image for you.

After their article search and search of author's website, the S-SME discussed the topic with the students in more detail, focusing on autoimmune disease and multiple sclerosis. The students incorporated this concept into their final game. The game of Group-2 consisted of a platform game where glial cells were captured to put onto the myelin sheath, which was deteriorating due to multiple sclerosis.

Students did not just use web searches for information but for looking at images as well. The S-SME also cautioned to make sure the images were from trusted websites. In one session with David and Anthony, a discussion about DNA led the S-SME to the computer to pull up a picture of DNA from one of the lists of websites that she provided for the students, as David was interested in using a background image for his game.

S-SME: What's that?

David: The protein you just talked about, histones.

S-SME: Histones, yes! … [Looking through the images.] This big rope here, gets wrapped around like this. And what do you think is making it stick in this funny shape?

Anthony: The proteins.

S-SME: Proteins! Absolutely right.

This image launched Anthony into asking questions about the deformities within DNA from the S-SME, a subject matter that neither student was using in their games but both got interested in discussing. Discussions within the group meetings with the S-SME branched to broader topics that may or may not have been picked up by students for their games. Thus, the research the students did on their own did not necessarily lead to searching for more research articles or for material for their games, but also for conversations. It was a time when students would ask questions about what they had discovered on their own, or else present their games to the S-SME as they had been completed so far. This time not only helped students with their own games, but the games of the other students in the discussion groups as well.

For example, in the discussion groups for the four students creating games on the neurotransmitter topic (Michael, Lawrence, Scott, and Ethan), they met with the S-SME together. One student, Michael, said that he found in his research online that the drug methamphetamine destroys neurotransmitters. Instead, the S-SME explained that methamphetamines actually mimic neurotransmitters and try to bind to neurotransmitter receptor sites. The four students gathered around a computer where the S-SME was guiding them through a research article on Lawrence’s computer.

S-SME: Okay, so if meth is acting like a neurotransmitter, how can you put that into your game? If you want to. Meth isn't really killing a neurotransmitter, is it?

Ethan: No.

S-SME: What's it doing then?

Ethan: It's imitating.

This information, which was initiated by Michael, caused the role of methamphetamines to be removed from his game, but it found a new place in Ethan's game. His final game focused on barring the methamphetamines from binding to the neurotransmitter receptors.

In Kafai and Ching's (2001) study of students making science games, they also mentioned they had a subject matter expert that students could email if they needed further information, but it was not clear how often students did this or if the content discussed with the expert helped student understanding. Indeed, in this study, students also had the opportunity to email the S-SME when there was not a scheduled meeting, but this was only done three times during the course of the workshop. The face-to-face interaction of the S-SME and students was the opportunity students needed most, undoubtedly because they could not only ask questions, but show off their games. The opportunity to meet with the S-SME each week gave them validation for the information they had found or the questions they still needed answered.

Indeed, the website available for the class also had the means for students to post messages to each other, but this feature was also not utilized. Given the close proximity of students to each other in the labs, if they needed to communicate with each other, it was also done face-to-face.

Finding 3: Students create video games through collaborative interactions. Students in the workshop were seated in close quarters in the computer lab, able to talk and socialize while they were creating their games. Much of their socialization centered on their games: watching the creators playing their own games, playing other students' games, asking questions from students on how they programmed certain aspects into their games, and even discussing elements of the science topics that were being portrayed in the games. The music coming from the computers while students played their games was a big attraction, not to mention the excitement of those playing the games, and many times there would be a group of at least two or three, if not more, students gathered around a single computer. Table 2 indicates that after referring to notes and conducting web searches, talking to their peers in the class was the next thing that helped students make their games.

Three styles of collaboration were apparent in this the game design workshop: collaborative interactions with students in the classroom, within groups that came together to make games, and with peer mentors.

Collaborative interactions with students. One student, James, was playing his game at his own computer when a few students and a peer mentor gathered around him to watch him play.

Wanda: That's actually pretty good.

Cameron: I know!

James, playing: And then I go back…[Pop-up screen appears.]

Wanda: That's actually pretty good, it's just that your spelling is terrible!

James: All right, let's see if I can pass the second level. It only has two levels right now, but I'm working on a third level, and we'll see.

Mentor: So, what are you shooting at?

James: White blood cells. The disease has taken over the body and the white blood cells have mistaken you over the disease, so they're attacking you.

Mentor: What are you?

James: I'm a nanobot.

Scott: Wait…you're destroying white blood cells? That means if you destroy the white blood cells, you die.

Wanda: I know, right?

James: They think that it's a disease and they want to eliminate the diseases from the body.

Scott: Why don't you just avoid them?

Cameron: I know.

Mentor: Wait, I'm confused. The white blood cells are trying to destroy the nanobot?

James nods his head.

Mentor: Because they think the nanobot is what?

James: A disease.

Scott: But if you destroy the white blood cells, the person dies.

James: For real?

Scott: Why don’t you just make it an avoidance game?

James: Well, we’re just trying to stop the disease.

Mentor: The nanobot is not really a disease, right?

James: No.

Scott says something softly, the mentor overhears.

Mentor: That’s a good point. Scott just gave you a really good idea. Why don’t you look it up and see what happens when you destroy white blood cells.

James playing his game attracted many students to his computer. He was proficient in programming and the students were impressed with his graphics. Once he started playing, however, the students realized the concept of his game did not make sense to them, as the goal of the game was to attack the body’s own white blood cells. They brought this to James’ attention. After this interaction, James set out to look up information on white blood cells and his next installment of the game featured white blood cells helping the “good guys” to attack bacteria, a direct result from peer feedback.

On another day in the lab, James was working on his game when Lawrence, who was seated behind James in the lab, was watching from his own computer. Then he suddenly got up and walked over to James’ computer.

Lawrence: How did you make that? The last part of the wall disappeared?

James: Yeah.

Lawrence: How did you make that?

James, still playing his game: All right, I’ll show you in a second.

James, pulling up his code: All right, you have the walls.

Lawrence: I have all the walls, I’m just trying to figure out how to take the last part off. When it’s all destroyed.

James: So just go to object, the wall, collision, laser, and then you change the instance, change it into a different one.

Lawrence: I’m talking about the very last one, after you shoot this one, and you have the last wall.

James: Like this? Like when I go from here, to that one?

Lawrence: To that one, yeah. From the second to the last one.

James: I just shot it.

Lawrence: You just shoot it? I thought you had it so when it pops up, it just destroys it like you’re shooting it.

James starts to play the game for him: Okay, you shoot that, and then shoot this, and then shoot this right here. [Pulls up the code from his game.]

Lawrence: Oh, okay.

Here, the students were specifically talking about a programming feature, where James was able to share the steps he took with Lawrence, in order for Lawrence to incorporate that part into his own game. Sharing code was a common occurrence in the lab among the 10 students who created their games individually. The interactions between students did not only happen between students who were sitting next to each other or students who shared similar science topics. Students liked to walk around the room to view what others were working on.

For instance, during an instructor lesson on how to destroy an object (in this case, an asteroid) inside a sample game, Dylan, who was in the DNA transduction group, finished his example and began walking around the room. Lawrence, in the neurotransmitter group, was frustrated with his work so Dylan sat down to the left of him and verbally gave him the steps in order to destroy the object.

David: Go to main1. Collide with smaller asteroid. Destroy instance, destroy other.

Lawrence: Thanks.

Next to Lawrence, Noah, who was in the gene regulation group, was seated to his computer and watching the exchange. It was clear that he was having troubles as well and wanted to get some hints. Dylan also noticed this and walked over to his game to help him. Lawrence ended up incorporating a destroy-object mechanism in his neurotransmitter game on his own, a lesson he was able to understand with the help of his classmate. Indeed, in the computer lab, students interacted most with each other to help out with the technical aspects of their games.

Collaborative interactions within student groups. In this workshop, there were also two groups that formed to create one game. The team of two, Group-2, decided to work on a myelin sheath game, a topic that other students also chose to work on individually. The team of four, Group-4, worked on DNA signal transduction, creating the only game on this topic. When asked why Group-2 decided to work together, Joseph in the group stated that he and Nick had been brainstorming together when they found that they had chosen the same topic.

Joseph: Well, we both kinda had the same idea. And he knew more about the game [programming] part and I did most of the illustrations, and so we started pulling our ideas together and worked together.

Joseph was one of the few students who had not had any experience working with the Game Maker programming before this workshop. He admitted that this one of the reasons it made him eager to work with a partner, but by the end of the workshop, he was also working in the Game Maker as much as his partner. They did give themselves clear roles in their team, as Joseph made original illustrations for their game which Nick incorporated into the programming.

The fear of lagging behind in programming skills also spurred the partnerships of Group-4, consisting of Dylan, Jayme, Mark, and Paul. Mark was worried about his programming skills, although he had started to sketch detailed diagrams in his Designer Journal from the beginning. Dylan noticed this and the two of them decided to work together. Jayme, who was seated next to Mark and Dylan, said that she was hoping to work with a group of students on a game because she was unsure of her programming skills, and decided to join the two of them. Paul, who missed the first two days of the workshop, chose to sit in the row next to this group of three, and became absorbed into their discussions. Soon, this group became established with four members, each with their roles: Dylan, programming; Mark, illustrations; Jayme, research and illustrations; Phillip, backgrounds and research.

These two groups that chose to work with their peers on their video games differed in terms of efficient collaboration. Group-2, perhaps because of their smaller size, worked well in discussing their ideas, assigning themselves tasks that both students accomplished, communicating with the S-SME and taking back these discussions to add to their game, and completing their game throughout the course of the workshop. Group-4 spent a lot of time working separately, and because of this, the first idea of their game did not come into fruition. They had a rough prototype of a game to show the S-SME during their first meeting, but after talking with her, they decided to go in a new direction at the end of the third week. They were able to have discussions with the S-SME about their science topic and did present a final, completed game, but because they spent so much time working separately in the beginning of the workshop, they had less time to make it. Thus, their final game did not have enough content to reflect an effort expected from a collaboration of four students during a 3.5-week workshop, and the students could not effectively explain the concept behind it.

Students were also placed into groups of similar science topics, where they had an initial group meeting on their own to talk about their topics, and then collectively met with the S-SME. During meetings with the S-SME, all students brought their own questions and games with them to openly discuss in the group setting, allowing other students in meetings to benefit from them as well. The answers to questions that one student asked in a meeting would find its way into another student’s game. This was one way in which the students collaborated with each other through the S-SME.

Collaborative interactions with peer mentors. In this game design workshop, eight peer mentors were on hand in the classroom to help when students had issues creating their games. Peer mentors were students who had already completed a game design workshop session with the same game making software, albeit without a focus of the science topic (Clark & Sheridan, 2010; Sheridan et al., 2009; Sheridan et al., 2013). They were typically two to three years older than the students participating in the workshop. Thus, peer mentors were involved with the game design workshop to help with the technical issues of the games. However, they were also encouraged to remind students to make sure they had their game information pages filled out correctly. When mentors came around to look at the information pages, they usually ended up staying to play the game and offer advice as well.

As the mentors were always in the classroom, they too were watching the progression of student games and would gather around computers when students would play their games to test them out or show them off. When Scott was playing his neurotransmitter game in the lab, it attracted some of the students. His game featured making sure the neurotransmitters got to the correct receptors before the methamphetamines tried to get to the receptors. One of the mentors came over and asked to play the game, while students and Scott watched.

Mentor: So those are methamphetamines…

Mark: Is that the axon? I mean not the axon, I mean…

Scott: It’s not the axon it’s the synapse.

Mark: What are these red things?

Scott: The neurotransmitters. I have to get them to the receptors and then the key level thing…

Mentor: Ah, and you know what I like? Your things actually look like receptors. So if the methamphetamines hit your nanoship, start over?

Scott: Yeah.

The students watched as the mentor continued to play and discovered a technical issue in the game.

Mentor, back to the game: Uh, you can’t escape! You can’t run, you can’t run.

Mark: Isn’t that a glitch?

Researcher: Is it stuck?

Scott: Yeah.

Mark: GLTICH!

[Scott has to get out of the game but takes the moment to show them the second level.]

Mentor: Oh, level two has got more neurotransmitters!

Mark: You know what, I’m really enjoying this.

Mentor: I am too, it’s terribly nice.

Mark: It’s very clear.

Scott: And that’s my game.

Dylan: Do the third level!

Mentor: We’re not going to do the third level right now. I’m going to need the science. So I need to know what meth is. I need to know what neurotransmitters are. What the synapse is. What those spinning circles in my body are.

Here, Scott had not yet made his game information page, so the peer mentor, who was playing the game, wanted him to make sure he identified all the images in his game for his game info. The students were able to understand that the neurotransmitters were traveling to their receptors when Scott pointed it out, but as the mentor noted, it needed to be explained in the game information page to give it context.

The peer mentors were quite helpful in this aspect: When playing the game, they would ask “What’s this?” in reference to the images and remind students that this needed to be explained. Peer mentors were given evaluation sheets to write notes to students if they played their games, and the most common comment for students in relation to the science content was to makes sure they labeled their images (see Appendix E). One peer mentor wrote for Cameron’s myelin sheath game that he “needs to make names for the gems because it is not understandable when you play the game.” The gem images in Cameron’s games were proteins, and after this comment, he labeled the different gem colors. Other comments from peer mentors to help students with the game involved using different colors to make better game visibility, adding background images, and levels being “not challenging enough” or “make it less difficult, I died within a few seconds.”

Student Understanding

Finding 4: Student games changed as their understanding of the science topic evolved. Every student or group in the workshop completed a video game on the science topic of their choice. Students presented their final video games during the last two days of the workshop, to their fellow students and to parents. Each student or group stood at a podium and played their game on a computer (reflected on a large screen facing the audience) as they narrated what was happening. After presentations, the S-SME and researcher then analyzed the games.

Students were place into three classifications of games: High, Medium, and Low. The table below shows the breakdown of games: five games were in the High group, four games in the Medium group, and three games were in the Low group. Refer to Table 4 for a list of students and their corresponding groups.

Table 4

Students and Their Corresponding Groups

Student/Group	Topic	Game Classification
Michael	Neurotransmitters	High
Noah	Gene Regulation	High
David	Gene Regulation/DNA	High
Group-2	Myelin Sheath	High
Cameron	Neurotransmitters	High
Scott	Neurotransmitters	Medium
Wanda	Gene Regulation/STDs	Medium
Lawrence	Neurotransmitters	Medium
Ethan	Neurotransmitters	Medium
Group-4	DNA Signal Transduction	Low
Anthony	Gene Regulation	Low
James	Myelin Sheath	Low

Students were placed in the High group if they were clearly able to explain their science concept, both in the game and the presentations; Medium if they had a good grasp of understanding but had made some minor mistakes in the game or explanation; Low if they had key issues in explaining their topic and/or portraying it in the game. It can be said that the students in the High and Medium group were able to understand their science concepts well enough to incorporate them into a well-developed game, but that students in the Low group were unsuccessful in making a game that could portray the science topic. However, for students in all groups, their games went through changes that were affected by how they understood their science topics. This was observed by noting changes to student games at three different points during the design workshop, as well as looking at supporting information from interviews, meetings with the S-SME, and field notes. Spitulnik, Zembal-Saul, and Krajcik (2005) assert that using technology-based artifacts is an ideal way to save work and make note of changes in artifacts to see how student understanding develops over time.

As students were asked to talk about how they went about making their game, it was revealed that presenting accurate information in their game was a priority to them.

> Joseph: We added more detail to it—the way it should be. In the beginning, it was going to be a fantasy game. But then we wanted to be more accurate.
>
> Researcher: What were the first thoughts you had?
>
> Anthony: Uh, about how to incorporate the science elements into it. How to make it legitimate.
>
> Researcher: What are you working on?
>
> Jayme: Really, I'm not just getting more information, because I'm confused on the subject and I want to make sure the game makes sense.

Having the "game make sense" in terms of the science became a focus for the students in the game design workshop, even when they were not completely comfortable with the topic. Instead of simply making "just" a game, they had a purpose to incorporate a science topic into their game, and it gave students a sense of responsibility to give accuracy to these topics. This was evident as students adjusted the features and content of their games as they began to become more familiar with their science topic.

As an example, when Michael was asked how he came up with his idea for his neurotransmitter game, he remarked that he had changed his first prototype because it did not work with the science topic.

> Michael: Yeah, one was, there’s one neurotransmitter and you’re trying to dodge the meth and you have to shoot at it. But that’s why I changed my mind, because I didn’t want to have a shooting mechanism. Because that’s not really scientific, to shoot. What would you be shooting at? So I changed it.

Michael had realized that he was not portraying his topic accurately in the first game, which was revealed to him as began to learn more about neurotransmitters. With his first idea, Michael had wanted to include an enemy in his game. He was stuck because he realized he did not know what an enemy would be to a neurotransmitter. He asked a student sitting next to him in the lab, “What destroys a neurotransmitter?” and they both did a search on the Internet and came up with the answer “meth.” Michael remembered that the scientist had mentioned something about drugs in her first lecture about neurotransmitters, so he walked into the first meeting with the S-SME armed with questions. This led into a discussion about how meth actually mimics neurotransmitters, so Michael dismissed the idea of meth “chasing” neurotransmitters in his game. Instead of worrying about enemies for neurotransmitters for the purpose of making a video game, he moved to looking at how neurotransmitters can be out of balance and the different factors that can affect their levels.

Creating a video game had caused Michael to need some kind of obstacle in his game, an enemy. Thinking about an enemy in terms of his science game made him realize that he needed to frame it in the context of neurotransmitters. This led him to look for some answers on his own and have discussions with the S-SME until he realized that he should be following a different route with his game, and turned instead to researching the levels of neurotransmitters. The first draft of his game was an important step to figuring out what he needed to know about his topic, and his game changed accordingly.

Wanda, although she decided to pick a game topic about gene regulation, began sketching ideas for a game that focused on destroying the sexually transmitted diseases syphilis and AIDS. The S-SME encouraged her interest and Wanda, with an interest in the game Space Invaders, decided on a shooting game in order to "get rid" of the diseases. The discussions the S-SME and Wanda had then led Wanda to think about what the body starts doing when it is infected with the disease.

S-SME: So who are you in the game?

Wanda: Based off of this?

S-SME: Based off anything, who are you? Shooting AIDS and shooting syphilis?

Wanda: Yeah.

S-SME: Well, who shoots AIDS and syphilis in the body?

Wanda: T-cells?

S-SME: Yeah, that's right.

Wanda: So you're the T-cell.

S-SME: Except for one crazy complication. HIV is infecting you, so maybe you got your T-cell fighting syphilis, and if AIDS gets too close to you, it can infect your ship…you can symbolize that in your game with AIDS sneaking around to infect you. Whereas syphilis, you're just shooting it. Syphilis, I don't know what it infects, but I don't think it infects T-cells.

After this discussion, Wanda realized the way syphilis and AIDS infect the body and the way they are treated would be quite different. She went back to the lab to do more research about diseases in the body. It led her to the decision to remove the disease AIDS out of her game and replace it with chlamydia. This introduced questions about how to destroy the new disease. Her subsequent discussions with the S-SME included the methods by which chlamydia and syphilis are treated in the body and how this can be translated to being "destroyed" in her game. Wanda's shooting mechanism then turned into shooting antibiotics in order to get rid of the diseases. Her new understanding about these diseases gave her game a specific and more accurate focus.

For students, a key part of building upon their understanding of their science topic happened during meetings with the S-SME. It validated what they knew about their science topic and also caused them to reflect again on new information, adjust their understanding of their topic, and thus adjust their game designs. Students benefitted greatly from having these discussions in groups with other students working on similar topics, as a question that one student brought up would stimulate new ideas for other students. For instance, a discussion between the S-SME and the two students in Group-2 about the myelin sheath led to researching together how damages to the myelin sheath can cause diseases like multiple sclerosis. This information was new to Cameron as well; his current game was based on repairing the myelin sheath with glial cells. As he researched more information on the multiple sclerosis when back in the computer lab, he added features to his game design to include information about multiple sclerosis in his game information page and adding a trivia section in his game about the disease.

The way discussions were handled by the S-SME was very important. The students were never told to do their game a certain way, nor were they ever directly “given” answers to their questions. Instead, if a student had a question about a certain concept, the S-SME would encourage the student to talk their way through their issues, and if they were stuck, the S-SME would then work though the problem with them, either by drawing diagrams on the board or going to the computers and researching the answer together. As in similar learn-by-design environments, the role of the S-SME here was to moderate discussions and be one, but not the only, resource of content for the students to use (Holbrook & Kolodner, 2000). Thus, because the S-SME never told them what they needed to put in their games, it was up to the students to take what was discussed in the meeting and reflect upon what was important to his or her own game.

Games were studied at three different points to make note of changes in them as the game design workshop progressed. Changes in this study were noted from the games, as well as from observations and interviews. Ten out of the 12 games created had some element of redesign in relation to the science concept in the game after the second week of the workshop, as shown in Table 5. The two games that did not show changes were made by David and Noah; David did not have a working prototype to show until the end of the workshop (although discussions with the S-SME also show that his idea for the game stayed the same from Week 2 and did not alter in relation to the topic) and Noah had the same game idea from Week 2 throughout the end with no change to the science concept incorporated in his game.

Table 5

Redesigns in Relation to the Science Concept

	Game Changes at Week 2	Game Changes at Week 3	Game Changes at Week 4
Anthony	Yes	Yes	Yes
David	No	No	No
Noah	No	No	No
Wanda	Yes	Yes	No
Cameron	Yes	Yes	No
James	Yes	Yes	Yes
Group-2	Yes	No	No
Ethan	Yes	Yes	No
Michael	Yes	Yes	No
Lawrence	Yes	No	No
Scott	Yes	Yes	Yes
Group-4	Yes	Yes	Yes
Total	10	8	4

Not all students were able to fully grasp the science concepts, even as their games and their understanding of the science topic progressed. James, who was placed in the Low group, struggled with his game about the myelin sheath. He was very excited about making a game and liked to look at what all the other students in the computer lab were doing. The pieces he liked, he tried to incorporate into his game, but he did not make the correct connections to his topic. During the first meeting with the S-SME, he showed and explained his first prototype.

> James: This is the glial cell right here that’s moving. And when it touches the black lightning, it gets slower. And I was thinking about setting a time limit where the glial cell runs out of energy and dies. But the real lightning would make it go faster… yeah. And if I were to make other levels, I would make DNA come up and try to block it off, or…
>
> S-SME: DNA try to block it?
>
> James: Yeah, like strands there, it’s not really trying to, but it is.
>
> S-SME: How did the DNA get out of its cell?
>
> James: Oh. Oh yeah. I didn’t think of that.

James had been listening to David talk about his game about DNA and decided to incorporate it into his game—along with the lightning that he referred to as electrical charges in the brain—without really thinking about how everything could relate together. The S-SME talked with him about the myelin sheath and glial cells and James said he would look into it more. In the next redesign of his game, he decided to take away the DNA but add in white blood cells. It is not directly obvious why he chose to add these, but it was clear that James did not know about them well. In the computer lab, he was playing his game for his friends and they asked him why the purpose of his game was to destroy the white blood cells. This led James to do some research on his own and find out that white blood cells can help the immune system and get rid of bacteria. In his final redesign of the game, the purpose was for the glial cells to get back to the axon, but James incorrectly added that bacteria were blocking the glial cells and the white blood cells had to destroy the bacteria in order for the glial cells to get back to the myelin sheath. Even though James had progressed in his understanding about glial cells breaking away from the myelin sheath and even better understood the role of white blood cells and its relationship to bacteria, he could not present these concepts in a way that made sense.

As Kafai and Ching (2001) note, a science-based game design approach "promotes students' ability to express their ideas and interests while integrating them within a science context" (p. 326). As students' understanding of the science topic changed and/or expanded, their ideas for the game design also altered. Although James's game, and the two other games in the Low category, did not portray the science topic accurately, 9 out of the 12 games were able to successfully incorporate their topic into their games.

Finding 5: The process of making a video game helped students articulate their understanding of the science topic. Students were introduced to the four science topics presented to them by the S-SME from the second day of the workshop. From that moment, the topic of conversation within the computer lab, between the students, and inside their game took on a very specific focus of science. Student vocabulary was now infused with all the scientific information they were taking in about the myelin sheath, neurotransmitters, genes, and DNA. Evidence of their growth in understanding their topic can be found simply by the way they talked about their science topics over the course of the workshop while they created their game; their confidence about their subject grew and they began to add more to the discussions that took place with the S-SME.

In the first days of the workshop during Week 2, after they had listened to the introductory lectures by the S-SME and selected their topics in Week 1, the students were still getting used to talking about their topics. Three students in the myelin sheath group were even having trouble pronouncing the term “glial” cells. It became apparent that during the initial discussions about their science topics, students were trying to remember what they had heard from the initial lecture by the S-SME, but clearly did not understand them. During the first group meeting with just the students who picked the same topics, a peer mentor asked the students about the science they would incorporate into their games.

> Nick: Well, I’m going to have…you have to fight pathogens inside the body, ’cause there are pathogens, you have to attack them from the back. And if they see you, they eat you.
>
> James: Yeah, like different neurons have different settings. Like, I know that there’s a neuron that makes you move your hands, like—Oh! Sensory neuron, uh, and I think it’s an input neuron, and something else.
>
> Cameron: I made a game that is about, uh, you have to shoot the cells and if the cells touch the body inside, um, it damages them and you die.

None of these students above used the concepts they just described in their games. They were just starting to think about their games and found it hard to explain their science topics, pulling in information that they thought might be relevant without researching it. It is possible that some students even believed they understood more of their science topic than they actually did until they were asked to explain it. Indeed, students were continually asked questions about their games and were given many opportunities to explain what was going on to the S-SME, thereby requiring of them to voice their understanding out loud.

One student, Michael, started his game on the topic of neurotransmitters, but it was clear he was still very unsure about the topic.

> Researcher: So, you have a little figure [in the video game prototype], what's that supposed to represent?
>
> Michael: This is the virus, and it can be the thing that you want to avoid also.
>
> Researcher: How does that relate to the neurotransmitter?
>
> Michael: Well, this is the neurotransmitter [pointing to screen], and you have to try to avoid the viruses, and stuff like that. And get to the cell body.
>
> Researcher: Okay. Do you remember what the neurotransmitter is?
>
> Michael: No, not really.

Michael went through at least two more cycles in the reflect-design-play-discuss process with his game and the topic before he settled on the one idea he carried through to the end. His final game was one of the games the S-SME praised most highly. How did he get from his initial point of confusion to a point where he could convey his thoughts about neurotransmitters confidently and accurately?

Michael did research on his own before he met with the S-SME for their first meeting. He had created a game prototype but was uncertain about a virus being responsible for “chasing” the neurotransmitters and found another route: methamphetamines, the drug he refers to as “meth.”

> Michael: See, I found that meth destroys neurotransmitters, so the object is to destroy the meth before it destroys you. ’Cause the meth is going to follow you, so you destroy the meth before it destroys you.

This idea was then brought up before the S-SME during the first meeting, as outlined previously, where the true role of methamphetamines was revealed. Michael decided to remove meth from his game. He switched instead to making a game about the level of neurotransmitters. During Week 3, he asked the S-SME about the level of neurotransmitters, a feature he had added to the new version of his video game, prompting a discussion between the two of them.

> Michael: Like, what lowers the level of neurotransmitters?
>
> S-SME: What lowers the level of neurotransmitters? Do you remember when I told you they had to be brought back into the axon?
>
> Michael: Yeah.
>
> S-SME: That helps lower the level—if that process is faster, what do you think happens?
>
> Michael: What do you mean, what happens?

S-SME: If they're brought back in to the axon faster, what happens to the levels?

Michael: It's lower?

S-SME: Yeah, it's lower.

Michael: But that's not a good thing.

S-SME: It depends, it could be a good thing or it could be a bad thing.

At this point, the S-SME starts to draw a diagram on the board of Michael with the neuron and labeling the axon and the neurotransmitters.

S-SME: How do they get there in the first place? Do you know where they are?

Michael: Channels?

S-SME: Uh-huh, we talked about channels, but they're doing something else.

Michael: The receptors.

S-SME: Where are the receptors? This is the neuron, this is the body of the neuron, and this is the axon. Where are the receptors of the neurotransmitters?

Michael: On the body of the cell.

S-SME: Yeah, that's right, there are the receptors. So how did the neurotransmitters get into the synapse?

Michael: They're released from the axon.

S-SME: That's right, that's right. So they're hanging out in these vesicles over here.

Michael was able to hold a conversation with the S-SME about neurotransmitters while adding to the dialogue, a vast improvement over the first days when he could not accurately give a definition of a neurotransmitter. Indeed, he started the conversation with the S-SME, identifying gaps in his own knowledge that needed further explanation. When he described his final video game that focused on keeping the level of neurotransmitters in balance, the S-SME found that he used correct terminology and was confident about his game.

> Michael: A neurotransmitter is a brain chemical that sends information throughout your brain and body. They're responsible for affecting your health…your mood, your concentration, basically anything that's hooked up to your nerves, whatever. And they have to be balanced; they can't be too high or too low. Things that affect the diet are, like, poor diet, stress, lack of exercise, lack of sleep, and drugs.

As someone watched him play his game, they asked what happens when the adverse elements in his game hit the neurons.

> Michael: It alters the levels—well in the game, it makes your health go down, which is basically the level of your neurotransmitters. In real life, it alters it and that can result in, like, you acting differently, and not really responding to your senses correctly.

Michael went from not understanding what a neurotransmitter was to being able to articulate how these chemicals in the brain can become imbalanced how that may affect one's body. He was able to focus on questions that were relevant to his understanding of the topic and engage in dialogue with the S-SME. Through his own words alone, we can follow the progress of his understanding of the science topic, a progression that came about as he worked through different stages of his video game (Figure 1).

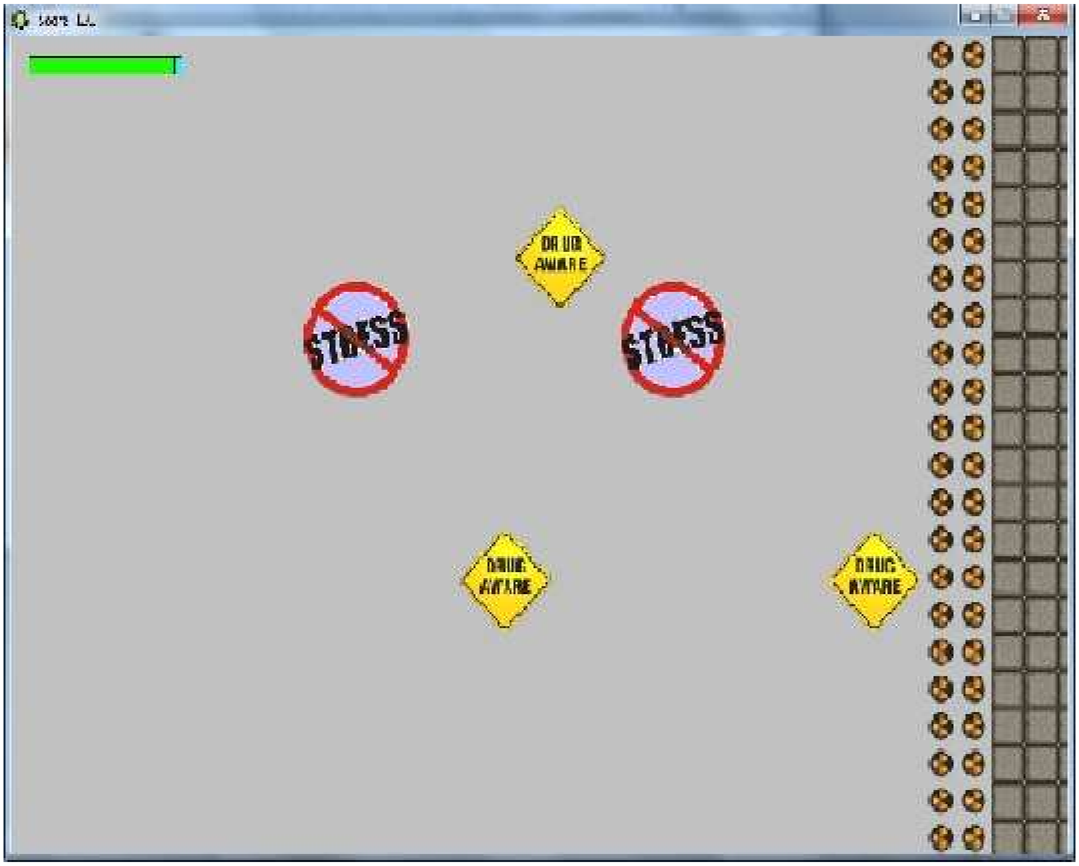


Figure 1. Michaels’ game.

Scott also worked on the topic of neurotransmitters, but took the route where he made a game about the neurotransmitters finding their way to the receptors. During the first week when he met with the S-SME, he was not sure of the correct terminology when showing her the prototype of his game.

Scott: You hit the neurotransmitters…you hit them and then they fall—no, they fall into the basket things, and when you get all of them, you win the game.

S-SME: Okay, that sounds reasonable. What are you demonstrating?

Scott: About the process of…how releasing the neurotransmitters can help you.

S-SME: What does it do? What does releasing neurotransmitters do?

Scott: It…what does it do…I had it here…[Looks at his notebook.]

S-SME: Well, the neurotransmitter is going from one cell to another, right?

Scott: Yeah. Through the axon, right?

S-SME: It leaves the axon, goes into the synapse, and then reaches the other cell. So why do you want something to go from one cell to another? Like, why do we care? What is the neuron trying to do?

Scott: Send a message.

S-SME: Yes! Send a message. It's trying to convey information, sends a message to the next cell. That's right.

The S-SME then asks Scott what the buckets are supposed to represent.

Scott: Glial cells?

S-SME: No, not the glial cells.

Scott: Receptors?

S-SME: Yes, receptors. What do receptors do?

Scott: They send the message.

S-SME: They receive.

Scott: Oh, they receive the message.

Scott was still learning about the neurotransmitters as he created his game. Once he and the S-SME had their discussions, he started writing in his Game Design Journal. A few days later, when asked about his game, Scott was more confident about his topic.

Scott: You're learning about how messages are being sent from one part of your body to the next.

Researcher: And how is that happening in your game?

Scott: The neurotransmitters are the messages and the boxes are the receptors. So once you get them all in your box, the message is sent.

As Scott progressed with his game, he listened to the other students discussing their own games in discussions with the S-SME. During Week 3, he asked whether he needed to have some kind of "obstacle" in his game, as his current game consisted of neurotransmitters getting into the receptors, without having an obstacle like methamphetamines in his game.

S-SME: I think it's an interesting game design question. My programmer and I got into an argument about it—he thinks if nothing is trying to kill you, then the game's not fun. And I think if it's cool puzzle, then the game is fun. You don't have to have something trying to kill you all the time. So I think it's fine. But what's the mechanic in your game, why is it hard to get the neurotransmitters to the receptors?

Scott: Because they bounce all around the screen.

S-SME: Oh, they bounce around, I see. And you kinda have to herd them.

Scott: Yeah.

S-SME: That's cool. So did you look at how real molecules move around?

Scott: Yeah. It was kind of like the bouncing around, just not as much.

S-SME: So you're imitating the way molecules bounce around. And you're right; the synapse has to be designed so that randomly bouncing molecules run into the receptor.

After the discussion about methamphetamines trying to get to neurotransmitter receptors, Scott decided to put these into his game as well. His nanobot guided the neurotransmitters to the receptors. If the methamphetamines hit his nanobot instead, they went to the receptors and the game is over. Scott discussed this with a mentor the day before his presentation, how only the neurotransmitters were to get to the receptors. However, on the day of his presentation, Scott changed the name of the obstacle in his game.

Scott: It's about neurotransmitters and how they help the brain send a message to the parts of the body. Neurotransmitters are chemicals that transport signals from a specific neuron to a target across the synapse. When neurotransmitters are in a cluster they are packed into synaptic vesicles. Okay, I'll just play…. To move use the arrow keys, to shoot use the space bar. This game is about a nanobot who tries to save the damaged neurotransmitters from the bacteria. To complete the task, you must put the neurotransmitters in the receptors by hitting them in the appropriate direction.

In his presentation, Scott used the term “bacteria” instead of the methamphetamines that had been discussed in groups and with the mentor the day before. It is possible this was done because students presenting games previous to him had bacteria obstacles in their game. It is also possible that Scott believed the term “bacteria” to be applicable to methamphetamines as well. The S-SME found his game to be quite good, as the game clearly showed neurotransmitters going into the receptors. She also liked the random movements of the neurotransmitters and that the game world was taking place in the synapse, as it does in the body as well. Despite the hiccup in the explanation of the game, Scott’s progress in understanding of neurotransmitters and his comfort in discussing the concept had grown from the first version of his video game to the final product (Figure 2).

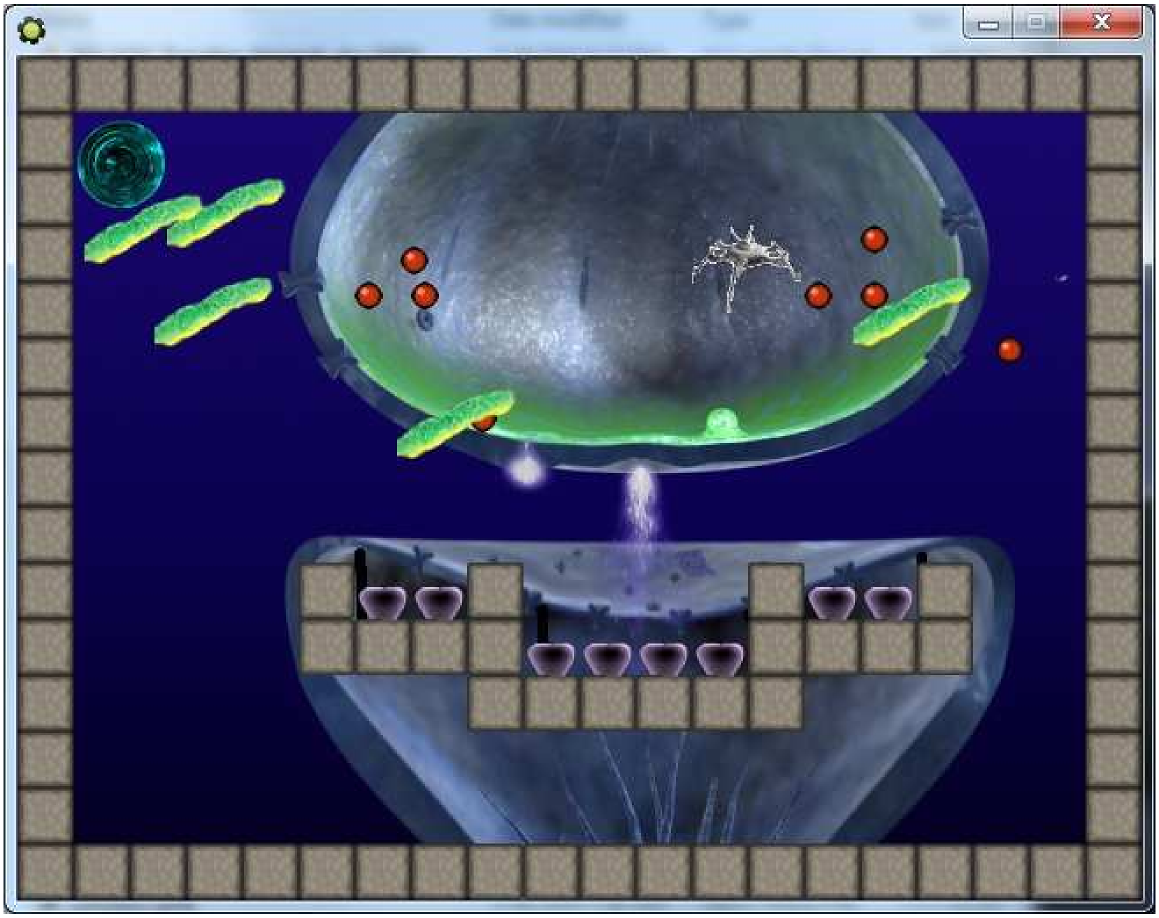


Figure 2. Scott's game.

Not only were students able to articulate their understanding of their science concept when explaining their games, but also when asking questions. Michael went from asking "What kills a neurotransmitter?" in Week 2 to wanting instead to discuss "What affects the levels of neurotransmitters?" during Week 3. Before the meeting in the Week 2, needing to know what killed a neurotransmitter had stopped him in the designing of his game because that was the player's goal. After talking with the S-SME and doing research, his next question was framed within the context of how neurotransmitters are actually affected in the body. Indeed, this becomes the pattern throughout the questions; they become more specific as the weeks progressed. Questions about bacteria become questions about *Staphylococcus Aureus*. Questions about glial cells breaking off the axon become more specific, How are the glial cells brought back to the axon? This is natural as students have gone through more discussions and done further research, adding more details to their games and to their understanding of their concepts.

Most students in the workshop progressed from being unsure of their topic to being able to speak confidently and for the most part, accurately, about their topic. The “for the most part” clause relates to if students, by the end of their final games, were able to accurately use terminology and describe the concepts of their science topic with no more than two minor mistakes, such as an incorrect term. The creators of 9 out 12 games were able to successfully discuss their topics by the end of the workshop.

The creators of two games, Anthony and James, stand out as having more difficulty in being able to discuss their topic even by the end of the course. Their games are discussed in the next section. One final game, the one completed by Group-4 consisting of Dylan, Jayme, Mark, and Paul, showed difficulty on focusing on one particular concept on which to base their game, let alone immerse in scientific dialogue. This group, the only one to select the topic of DNA Signal Transduction, showed moments where they engaged in dialogue with the S-SME during one week, but the following week could not work that into an idea for their game.

When it came time for the first meeting with the S-SME, Group-4 had a shell of a prototype, which did not have any images or a clear concept, but had the workings of “tractor beam” code which was to be incorporated into their game. However, Mark had drawn a picture of what he believed their game would be about.

Mark: So, this was as best as I could do from his drawing. It’s basically, I guess, the way it signals through the axon and the whole, um, submitters, and this is the dopamine, stuff like this. This was supposed to be the dopamine.

S-SME: Okay, so this is the terminal, this before the signal comes, and this is the terminal after the signal comes?

Dylan: Uh-huh.

S-SME: And what are the colored dots?

Dylan: Those are the signal packets that have then fused to the wall and released into the synapse.

S-SME: Yeah. These are synaptic vesicles.

Dylan: Yeah, that.

S-SME: They’re also bound by the membranes. The same membrane I drew over there? So we call them membrane-bound vesicles. So the neurotransmitters can’t get out because of the hydrophobic barrier.

Dylan: This is them, inside of their cloud…

S-SME: They’re in a cloud?

Dylan: Like, after they’ve been released, it’s focusing more than they are moving across the synapse…. This right here, there’s supposed to be a cell right here. Um, there’s receptors in the cell, and you got to, like, click and drag each of these to the right receptor, and if you get one wrong, the entire game restarts.

It appeared that Group-4 had a concept to work with and even though they could not correctly identify all the terminology yet, they were trying to formulate the ideas by talking with the S-SME. However, they did not continue with this idea after the meeting and still could not produce a working game. The next time they met with the S-SME, they had a completely different idea, and it became apparent they were not confident about the new topic as well. They wanted to focus on signals, but mixed up electrical signals with chemical signals. The S-SME was even confused as to what this group was trying to do.

S-SME: I want you to tell me more about the mechanism of your game. What am I supposed to learn when I am playing your game?

Dylan: How to signal DNA.

S-SME: Okay. So…you're talking about electrical signals and the receptor on the next neuron, but you haven't talked about DNA at all.

Dylan: I don't really know.

S-SME: Yes, this whole scenario that I've been telling you about is really just to put the signal on the next cell. Seconds. So that signal to the DNA doesn't go that fast. So what do you think you're learning, really?

Mark: I think I know what you're saying. I think we really did forget about the whole DNA thing. The object of the game would be, actually having a level with DNA spread out, or whatever, where you actually take it to the

DNA. Maybe there's a shape like this that actually fits in, if that makes sense. I know we drew this, but I don't really know why. [Shows it to the S-SME.] I think basically, all we had, getting different—the nanobot was putting different things in the components, but we should have the nanobot go through a level of stages where he finally arrives at the DNA. So then he combines with the DNA, so it gets…

S-SME: If you do want to signal to the DNA, you're going to have to figure out a way to get from the receptors down to the DNA. So you could make the game all in the synapse and finding receptors or you could make a game about getting in the DNA. And if you do go in the DNA…your question is, how do proteins bond in the DNA?

The Group-4 was still unsure how to progress with their work. However, one of the group members, Mark, had drawn images in his Game Design Journal from a video he had watched about signal transduction, which the S-SME noticed.

S-SME: You have a picture there. What's that? The membrane, or the DNA?

Mark: I think DNA. It was from a 3D YouTube video. And basically, these little things were being taken from here, and it opens and drops through this thing, and this thing travels and gives it to this, which gives it to this, and so on, and it actually goes inside this humungous thing.

The group decided to model their video game after this YouTube video. It became the basis for their game, showing how proteins became activated and passed their activation on. However, as the presented their game on the final day, it was clear by their explanations that did not completely understand the process and were not comfortable talking about it (Figure 3).

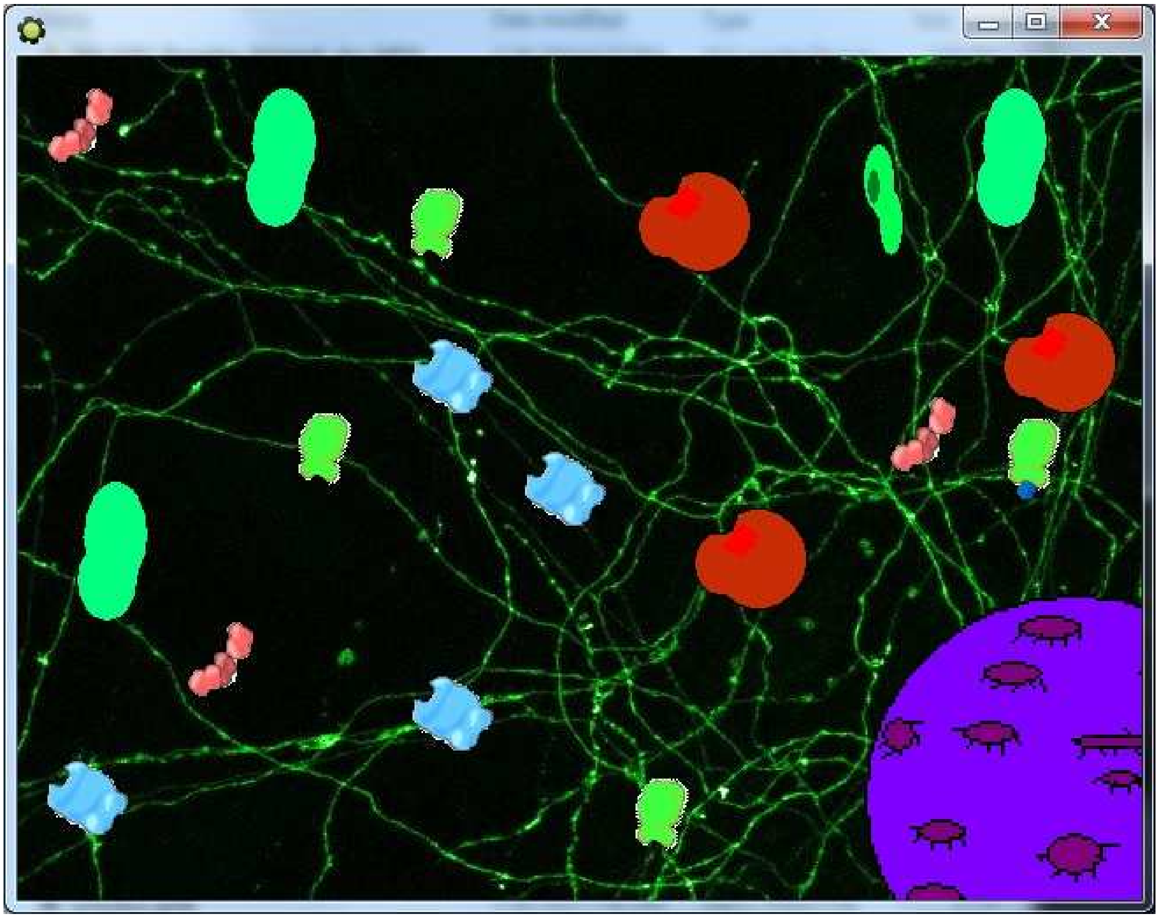


Figure 3. Group-4's game.

Student Attitudes

Finding 6: Student attitudes toward science and making video games.

Students were given pre- and post-surveys to determine attitudes toward science as based on the modified version of the TOSRA: Test of Science-Related Attitudes (Fraser, 1981).

The scales used for this study were Adoption of Scientific Attitudes (ASA), Enjoyment of Science Lessons (ESL), and Career Interest in Science (CIS). Refer to the Appendix A for the questions given. The results are outlined in Table 6.

The survey used a 5-point Likert-type scale ranging from 5 (Strongly Agree) to 1 (Strongly Disagree). As each scale had 10 questions, the minimum score of the means would be 10, the maximum 50. Although each scale shows some improvement over the means from pre- to post-survey, with the most improvement belonging to Career Interest in Science, there is no statistical significance in science attitudes for $\rho \leq 0.5$. Individually, no question showed statistical significance either.

Table 6

Student Attitudes Toward Science, Modified Test of Science-Related Attitudes (TOSRA)

Scale	Pre-survey Mean	Pre-survey *SD*	Post-survey Mean	Post-survey *SD*	*p*
Adoption of Scientific Attitudes	36.38	4.63	36.5	4.95	.92
Enjoyment of Science Lessons	32.5	8.83	32.63	6.44	.92
Career Interest in Science	27.94	5.65	29.94	5.47	.13

Students were also given five diagrams as submitted by the S-SME (see Appendix A) to determine whether “I would be able to understand this diagram if I read it and thought about it” based on a 5-point scale. The results are outlined in Table 7. There is no statistical significance in the results. However, results do indicate that student answers to each of the five questions improved from pre- to post-survey.

Table 7

"I Would Be Able to Understand This Diagram if I Read It and Thought About It."

	Pre-survey Mean	Post-survey Mean	Δ	*p*
Diagram 1	3.06	3.5	.44	.17
Diagram 2	3.25	4	.75	.10
Diagram 3	3	3.06	.06	.84
Diagram 4	3.19	3.31	.13	.76
Diagram 5	3.31	3.81	.5	.07

For video games, students were given a modified version of the Intrinsic Motivational Inquiry instrument (Deci et al., 1994). The results are displayed in Table 8. Two questions here showed statistical significance, under the Perceived Competence subscale.

Table 8

Video Game Attitudes With Reverse Coding

Question	Pre-survey Mean	Post-survey Mean	Δ	*p*
I enjoy making video games very much.	5.44	5.44	0	1
I think I do pretty well at making video games, compared to other students.	4.81	5.13	.32	.31
I believe making video games could be of some value to me.	6	5.88	-.13	.61
Making video games does not hold my attention at all. (R)	6.06	6.38	.32	.24
I am pretty skilled at making video games.	4.63	5.25	.62	.04
I think making video games is important to do because it can help me get a job.	6.06	5.63	-.44	.09
I think making video games is a boring activity. (R)	5.88	6.31	.44	.13
I think I am pretty good at making video games.	4.88	5.25	.37	.01
I think making video games is an important activity.	5.06	5.19	.13	.54
I would describe making video games as very interesting.	5.88	5.69	-.19	.38
Making video games is an activity that I can’t do very well. (R)	5.63	5.8	.18	.46
Making video games is fun to do.	6	5.94	-.06	.67

Note. (R) = reverse coding.

Students were also asked in their surveys if they liked making games about certain subjects. The results are outlined in Table 9. The results with the most statistical significance were Science and Sports. Interestingly, on the pre-survey, every single student gave the same weight to their answers for all subjects, indicating no preference for one subject over the other. On the post-survey, no one did this and ranked the subjects according to what they preferred. Most subjects did improve overall, with Science, Art, and Sports having the most improvement.

Table 9

Making Games About Academic Subjects

I like making games about:	Pre-survey Mean	Post-survey Mean	*SD*	*p*
History	2.94	3.25	1.78	.49
Math	2.94	3.13	1.97	.71
English	2.94	2.81	2.70	.86
Science	2.94	4.06	1.67	.02
Art	2.94	4.06	2.45	.09
Languages	2.94	2.94	2.42	1
Sports	2.94	4.94	2.81	.01

Students were also asked about how they felt about the game design program to gauge what they thought about making games and making games about science. Ten students were interviewed and all of them said they enjoyed working on their science games. Seven of them said that they would want to make games about science again; of the three who did not immediately say they wanted to do it again, two of them said science would not be their first choice as a game topic and the third one said it was more interesting learning the science from the scientist than from making a game.

Researcher: Did you like making the science game? You can be honest.

Noah: It wouldn't be my first choice, in terms of a game to make, but it was an interesting challenge. Having an actual topic. Having to build a game around a specific topic.

Researcher: What other topics would you want to make games about?

James: I think we should just stick to science, but maybe a different science that no one knows about. I don't know. Something cool.

Jayme: Well, talking with the scientist was good. Talking with someone who is actually in that career choice, I think that's a good thing to do. Because then you get that first hand-to-hand, like talking to them, interacting with an actual scientist.

Researcher: Would you change anything about the program?

Michael: Probably, another year, different subject?

Researcher: What subject—

Michael: No, the same subject, but other parts.

Researcher: So you would want to still do science, but a different topic?

Michael: Yeah.

Researcher: Do you have any suggestions?

Michael: The brain. I don't know. Since science is so broad, it would be perfect.

Summary

This study immersed students in a constructionist learning environment with learner-supported tools to design video games on an unfamiliar science topic. It found that students used a number of strategies when designing their games: Students based their games on games they had already played; they conducted research on their topic by use of tools such as their journals, web searches, and used the S-SME as a point of validation for their ideas; they collaborated with their peers while making the games. In addition, it was found that student game content evolved as they began to understand their science topic more and that the process of making the video games allowed students to articulate their understanding of the science topic. These findings are further discussed in the following chapter.

5. DISCUSSION

This research study provided a constructivist game design environment for students to design their own video games based on an unfamiliar science topic. It was led by mixed methods research; qualitative and quantitative data were collected through field notes, student interviews, recordings of the meetings with the S-SME, pre- and post-surveys, student Game Design Journals, student final video games, and final presentations. Analysis was guided by the conceptual framework of the study and grounded theory methodologies. The study was guided by the following research questions:

RQ1: How do students create video games on science concepts about which they are unfamiliar?

RQ2: How does designing educational science games affect student attitudes toward science and video game design?

The research questions were broken into the following subquestions:

RQ1a: What strategies do students as designers use in order to understand the science concepts?

RQ1b: How do students exhibit their understanding of the science concepts through their video games, the design process, and their explanation of these?

RQ2a: How does the game design experience affect student attitudes toward science?

RQ2b: How does the game design experience affect student attitudes toward making video games?

Student Strategies

RQ1a: What Strategies Do Students as Designers Use in Order to Understand the Science Concepts?

This question looked at finding what strategies students in a game design environment used in order to create a video game based on a science concept with which they were unfamiliar. What this required from the student was to (a) understand the science concept and (b) design a video game based on this concept. Simply designing a video game required that the students be actively thinking about multiple issues. Clark and Sheridan (2010) point out that when designing games “students are challenged to become metacognitive about how games function: how games use audio, visuals and text to communicate ideas, what helps users understand a game, what makes a game fun” (p. 127). Students must consider such ideas in addition to the technical aspects of the game, positioning them to use critical thinking and problem-solving skills (Brennan & Resnick, 2012; Denner & Werner, 2007; Kafai, 1995; Robertson & Howells, 2008; Sheridan et al., 2009). Now, in addition to designing a game, students were given a topic on which to base a game, a topic with which they were unfamiliar and needed to understand better for their game. Prior research on game design integrated with educational content (Baytak et al., 2011; Ching, 2000; Harel, 1990; Kafai, 1995) has shown that it is necessary for students to take time to with the topics first in order to be able to understand how the topic can be integrated into the game.

Students create video games based on games they already played. As detailed in Finding 1 (Chapter 4), students in this study created video games based on games they already played. Prior research has also found that students have modeled game design on commercial games and films (Baytak, 2009; Kafai, 1998; Robertson & Nicholson, 2007; Yarnall & Kafai, 1996). Kafai (1998) mentions that one reason for this could be the influence of popular media, which she found especially prevalent in boys. Boys were prevalent in this game design workshop (14 boys and only 2 girls), so this could be the case. However, all students in this game design workshop indicated that they played video games, and 11 of 16 students stated that they played every day. Therefore, all students were already entering the game design workshop with experience and influence from professional games.

The desire to base a game from a professionally developed game proved to be daunting at times for the students. In the popular online game Bejeweled, different-colored jewels fall down, and it is the player’s goal to match up the correct jewels to make a chain that will disappear, lest too many jewels fill the board and you lose the game (similar to Tetris). In one student’s game, David had the nucleotides (A, C, T, G) fall down, with the player’s goal to match them up correctly as they match up in the DNA helix. However, David found the programming challenges well beyond his skill and worked with peer mentors and instructors throughout the entire program to complete it. Kafai (1995) acknowledges that students designing games will have difficulty even expressing their initial ideas and “it would be unrealistic to think that they could take into consideration all the aspects that would be involved in planning and designing a game” (p. 81).

By choosing to base their own games on games they had already played, students alleviated the some of the problem of planning and designing a game from scratch. Using familiar games also introduced well-known game mechanics into the student-created games, from replacing shooting bad guys to shooting diseases with antibiotics, to traversing a maze like Pac-Man in order to turn genes on and off. For these games, the students are not giving an accurate or literal representation of the science topics. Prior studies do acknowledge that students create games based on educational content without complete visual accuracy; Kafai and Ching’s (2001) study that focused on students creating games on neuroscience found topics most often consisted of animated representations. Especially for more complex educational topics like science, the level of accuracy expected would be out of the scope of what young students would be able to present. Instead, in this study, students are giving a stylized interpretation of their understanding, and basing a game around it. This approach to game design is referred to as an artistic or architectural design, as opposed to an engineering design (Kafai, 1995; Kafai & Ching, 2001).

However, there are still some issues to take into account when students create games about science using familiar games and game mechanisms. Dickey (2005) states that the primary goal of video games is entertainment, engaging the player through strategies such as role play, narrative, and challenges. For students creating games, the need to provide an entertaining game as interesting as the one they are basing their game on could become more important than the science topic in the game. This was the experience of James, who wanted an exciting game with lots of challenges, and thereby continually added elements to his game that contradicted the science content. In this case, creating a game to explore a science topic impeded the ability to actually gain understanding. Additionally, because students are more familiar with the structure of games rather than the unfamiliar science topics, when assimilating new information about their science topics, there is the possibility that students accommodate the information only within the context of games. For example, Wanda created a game about eliminating disease from the body, based on the game Space Invaders. She modeled shooting enemies with bullets by shooting the disease with antibiotics. Even as she began to learn more about the diseases and the types of antibiotics that could cure them, she continued to incorporate this information by eradicating the disease through antibiotic "bullets." It begs the question of what else Wanda would have been able to explore if she was thinking beyond the context of the method of the game she had chosen to model.

These examples serve to demonstrate how students' preconceived notions of games and game structure may have in fact limited the scope of science exploration students could achieve, and in the case of James, definitely did. However, this does not apply to all the games made. To counterbalance James' experience, there is Michael's experience, who initially started out making an entertaining game to prevent enemies from destroying neurotransmitters, but realized this did not make sense and changed the game to better accommodate the topic.

It is a natural outcome of asking students to create a game that they would want to make it fun and entertaining. In Kafai's (1995) study on children creating educational video games about teaching fractions, she compared it to Harel's (1990) of children making instructional software on the same topics, and found that there was more playful and more fantasy-based content in the game designs. This kind of creative freedom in creating video games is one of the reasons for having students make games for learning academic content, or design skills, or computer science (Baytak et al., 2011; Click, 2014; Kafai & Peppler, 2012). Yet it must also be considered that this creative freedom in games of novice game makers, such as the ones in this game design program, may require a sacrifice in other areas.

Students gather information about unfamiliar science topics through Game Design Journals, web searches, and discussions with a science expert. Students in the game design workshop were given access to information and collaboration tools to help them understand the unfamiliar science topics presented to them. The topics were presented as unfamiliar so that all students could start from relatively the same starting ground of exploring their science topic.

Students only met with the S-SME once a week, so the rest of the time, they were left to use the resources given to them so they could research their topic and work on their games. Some resources were used often, such as the Game Design Journals. These journals allowed students to take notes and draw initial designs of their projects, giving them an opportunity to reflect on the ideas that were starting to form or to expand on current ideas. Allowing for reflection allows students to monitor their own thinking and make sense of the content (Davis, 2003).

One resource that was underutilized was the website for students to post questions and share files. This is not surprising, as students tended to ask questions within the lab face-to-face, and instead of sharing files, students would once again share tips and help with games at each other's workstations. On the website, a list of trusted websites and journal articles was highlighted for the students where students could look for information about their science topic. Checking websites like Wikipedia would be fine for the first round, but because anyone could put information on that site, it was suggested not to use the site as the only source. Instead, students were urged to take the information gained from Wikipedia and look through trusted sites and journals for further, validating information. However, this proved to be difficult for the students. The information found on professional websites and journals was confusing to read on their own.

What occurred instead was that students would present the information they found from websites like Wikipedia for the S-SME to validate. Many times, this would include the S-SME looking through journal articles alongside the students, explaining what the journal was talking about, and drawing diagrams for them. Students knew they should not solely rely on Wikipedia or searches on Google, but they needed help with deciphering other websites and even some of the information they found on Wikipedia, so they brought it to the source they trusted most: the scientist.

These 12- to 16-year-old students are not alone in finding websites such as Wikipedia to be the most useful in conduction preliminary research on topics. A study on first-, second-, and third-year medical students found that they used Wikipedia and Google for biomedical related searches far more often than university libraries or online medical libraries, even though they themselves rate these websites the least reliable (Judd & Kennedy, 2010). It appears that the easy accessibility of finding answers on these websites outweighs the knowledge that it is not the best route to take; thankfully, the students in this study were able to discuss their results with the S-SME.

Students not only prepared for meetings with the scientists by having questions ready, they also incorporated the information on their science topic into their games and brought prototypes to the meetings as well. The questions by the students led the group discussions in the meetings; the games gave the S-SME insight to where the individual students were heading and what issues they had with their topics. This allowed her to scaffold her advice on the specific information a particular student needed in order to continue on his or her game. These meetings were ideal for the S-SME to support the learning of the students, and then allow the students to once again take the initiative in creating their own games. For a constructivist learning environment, this constant support is crucial (Jonassen, 1990).

Students create video games through collaborative interactions. Playing video games is a social experience for teenagers (Lenhart et al., 2008). This study found that making video games is social experience as well. Similar to the study by Robertson and Howells (2008), students were given different opportunities to engage in social interaction. They worked in the same computer lab during the workshop, often times wandering to each other’s computers to watch what others were doing and to play each other’s games. Students working on games at their computers would often become excited or frustrated and verbally expressed this, drawing a crowd to their work station. The video games also incorporated music and sound effects, which again drew students to watching others’ games. It was observed that students interacted most often when asking about certain types of game features to add to the game, thus talking more about the game design in the software program rather than the science concepts in the games. Likewise, Yarnall and Kafai (1996) also found that in their study of children making ocean-related science games, the students did collaborate together but focused more on the programming aspects in their conversations than the science content. This finding differs from Kafai and Ching’s (2001) study on students making neuroscience instructional software, where they found that students did engage in science discourse when discussing content screens. However, unlike both these studies, students in this study were given the option to work on games alone or in teams, and the majority of students in this study worked on games by themselves, in addition to one group of two members and one group of four. Thus, when students were engaged in game design and thinking about their science topics, most students were working alone.

This study refers to the interactions between students where they worked together and influenced each other’s games as collaborative interactions. The traditional methods of collaboration consider a group of members involved in a social engagement and negotiation to share knowledge and ideas while working together toward one project. In the case of game making in this study, however, students are working on projects with similar topics and the same goals, but working individually. In this type of setting, this can make it tricky when speaking of collaboration between students on their individual projects. Some studies identify collaboration as when students share ideas and offer suggestions for games together even working on separate projects (Baytak, 2009; Robertson & Howells, 2008). Baytak (2009) further classified his observations of student collaboration as times of help-seeking, getting peer feedback, and distributing expertise. Yet because these sessions between students are informal and rely more on helpful suggestions rather than working together to provide a solution, it deems it necessary to distinguish these episodes from traditional collaboration. Kafai and Harel (1991) describe the setting of the open computer lab where fourth- and fifth-grade students created instructional software with LOGO as a place where students could work together for periods of time, if they wished, or work alone. In this environment, students engaged in social interaction, code was available to be viewed and shared, and ideas and knowledge “floated” between the computers. They referred to this as “collaboration through the air,” a term used only in this study to refer to such a specific flavor of collaborative process, but it serves as a great description for the collaborative efforts in a game-making environment and it provides an example as a way to distinguish the social and helpful interactions of students amongst each other. Students in this game design workshop participated in collaborative interactions similar to the one described by Kafai and Harel (1991); most prevalently, through sharing code, playing each other’s games, and giving helpful advice about the technical aspects of the games. Collaborative interactions also occurred during meetings with the S-SME, where individual students with similar topics met at the same time to discuss their work, and would end up providing information for each other's games as well.

However, there were two examples of collaboration in the more traditional sense in this study as well. Two groups were formed of their own accord to work together on a shared game, one that worked well together, and one that could not come together successfully. Group-2 consisted of two members and they were able to come up with an idea together, work on separate parts of the game and merge them successfully, and discuss new ideas with the S-SME and incorporate these ideas into updated versions of their game. Group-4 consisted of four members, and they could not agree on a solid idea for their game from the beginning, which led to the failure of being able to identify separate parts for the members to work on which would contribute to the game. This may very well be attributed to the number of members in the team and the necessity for them to have been able to communicate together before embarking on a shared project. These issues between Group-4 highlight the distinction between a collaboration between members trying to work together to make one game, as apart from individual projects having been influenced by comments and shared pieces of code from fellow students in the lab. A collaboration within a group requires members to engage in discussion in order for each member to take responsibility for contributions in a game, while in a more informal collaborative interaction, as observed in this study, students do not need to take or give credit for ideas or suggestions that are shared. Instead, they are given freely and taken as needed, and still may create a meaningful impact on the game.

Collaborative interactions occurred not only between the students in the game design workshop, but also from peer mentors to students as well. The peer mentors helped greatly with the technical issues of their games because they had been through the program before. Previously documented studies confirm that the existence of older students with experience in game design can add to the development and richness of student games (Ching, 2000; Clark & Sheridan, 2010; Kafai & Ching, 2001; Marshall, 2000; Sheridan et al., 2009).

Student Understanding

RQ1b: How Do Students Exhibit Their Understanding of the Science Concepts Through Their Video Games, the Design Process, and Their Explanation of These?

This question sought to examine how students were able to portray their understanding of the science topic as they experienced the game design process and completed their video games. The first part of Research Question 1 concentrated on the strategies the students took in creating their games about science; this part is interested in the way the students were able to portray their understanding of the science topic in their completed games.

This research study did not set out to teach students about science and then test them about what they learned. Rather, it introduced students to science topics they had not yet been exposed to in their schooling and immersed them in a learning environment where they could explore the topics through video game design. By using topics that were unfamiliar to the students, all students started from relatively the same place in their approach with the content, and it provided the opportunity to observe how they engaged with new topics. With the aid of the S-SME, the student video games and final presentations—where students played and discussed their games to the class—were analyzed for science content and explanation. Looking through the chronological order of the individual or group's dialogue and design from creation to completion of the game helped establish what kind of understanding students were able to grasp of their science topic, and how they were able to represent it. It also provided for an opportunity to observe the design process the students went through.

Student games changed as their understanding of the science topic evolved. Kafai (2005) remarks that in learning-by-design approaches "learning happens best when learners are engaged in creating artifacts representing their ideas" (p. 29). It is the driving theory of constructionism, that the learner is building external knowledge structures through creating an artifact (Papert, 1991). Thus, in examining the artifacts that students have made, one can see the representations of their ideas and the meaning they have created. If the student then makes a change to the artifact, then one can see how the original ideas may have also changed.

In order to see the evolution of student understanding, one can follow the trail left by the different versions of the games. As the games were not literal translations of the science topics, it was necessary to use the games, conversations with the S-SME where students explained their games, observations of students talking about their games, and interviews to help decipher what was happening in the game and what students were capable of explaining at the three different points of analysis, done at Week 2, 3, and 4.

In examining these games at these three points, and indeed in looking at student work throughout the game design workshop, it was clear that students were involved in the iterative process of design. This cycle includes time to for reflecting on the game to be created, designing the game, testing the game, and having a period of discussion about the game, and indeed previous research confirms that students use some version of this process for design (Baytak, 2009; Flannagan et al., 2005; Kolodner et al., 2003; Resnick, 2007; Robertson & Nicholson, 2007; Salen, 2007). Students in this study showed moments where they took time to think about their games in their Game Design Journals, designed the game through sketches or the Game Maker software, tested it out for technical issues or for others to see what they had made, and discussed their games with peers, mentors, or the S-SME. Then they would take this information and apply it to another stage of the cycle, whether to think about a new idea or to jump right in and program another feature in the game. Robertson and Nicholson (2007) state that students do not necessarily visit the stages of the iterative design cycle in order.

This design process that was observed occurred not from any kind of instruction that asked students to cycle through specific stages when creating their artifacts, but rather from the organic procession that came out from game making. Students needed to give thought toward their games before creating them; this was initially observed in Game Design Journals through notes and sketches, but continued to be observed through the new ideas and features that were added to the games. Creating the game and testing it for feedback and errors, or debugging, was needed to ensure that a game is working properly. In learning the software Game Maker in previous workshops, and again as a reminder in refresher lessons during this game design workshop, students had always been advised to check through work periodically by running their games to make sure their code was functioning according to their specifications. It is not enough, however, to simply have the opinion of the game creators themselves for how a game works and functions; in game design, feedback is also needed from a client or from users to let the designer know what works well. This is where collaborative interactions with the peer mentors helped with the functioning of the game; mentors would help students when stuck on properly working code or help them with suggestions on how sounds, graphics, or elements of game play (e.g., use a mouse instead of a keyboard) could better be incorporated into the game. The interactions were spontaneous and occurred as needed, but students did enter a *discuss* phase with the mentors as it was occurring. This time with the mentors, and at times even with students in the class, was vital as a jump-start into another reflect or create stage in design, and propelled the momentum of the completion of the game.

It is interesting that the students' understanding of the science topic also went through a similar iterative cycle. In considering the technical aspects of the game, the *discuss* stage of the design process was driven by peer mentors, instructors, and fellow students. However, in terms of thinking about the content of the topics and its incorporation into the game, this phase of the *discuss* stage was driven by the weekly meetings with the S-SME. Here, the data shows that students were asking questions about their topic and leaving the meeting with some new information to enter the *reflect* stage, which would then show up in their game. Although the meetings with the S-SME were scheduled once a week to provide an opportunity for students to ask questions, the meetings were student-led and introduced ideas that were emerging from student work, allowing for students to take in the discussion and gain new information. The continued iterations of the design cycle that were fueled by the S-SME meetings were observed to have happened through student-led initiative; that is, students were not instructed to change their games after the meetings, nor did the S-SME tell them to change their games, but rather offered them suggestions and guided them toward the answers they were looking for. This kind of scaffolding helped students reflect upon the new information and drove the elements of change in the game content, as well as elements of change for understanding the science topic itself.

The iterative cycle of design for both the game and the game content, although distinguished here separately for discussion purposes, occurred simultaneously, as students could not separate their thinking of design from the content (Kafai & Ching, 2001). Thus, when students were reflecting upon their game design, they were not only thinking about how to design a game but how to design a game about their topic; likewise in design, testing, and further discussion stages of the design cycle, the science topic could not be separated from the game. Robertson and Nicholson (2007) note that "it is common for designers to return to previous stages as their ideas evolve" (p. 3). As students learned something new about their topic, it would add to their understanding of their topic and cause them to return to another stage of the design cycle and, as the artifacts show, the games would change.

Spitulnik et al. (2007) also found that students engaged in creating multimedia artifacts on science were able to construct meaningful knowledge from the design process and that the development of their understanding could be followed from the progress of work from their artifacts. As learners in a constructionist environment build knowledge through creating an artifact, students in this study improved on their understanding of science topics by creating video games, and the development of this understanding could be followed through the changes in the games. As the data shows, as student understanding changed about the topic, so did the portrayal of the topic in the game.

Kafai and Welsh (2007) note that iterative development helps students review and redesign their artifacts, which is then particularly helpful in assessing the content of artifacts by students themselves, peers, and teachers. The iterative cycle allows for clear points that can be observed where games change from one stage of development to the next, and from this, the progression of student understanding can be observed as well. Following the progress of student artifacts in this study made it possible to place the games into categories of High, Medium, and Low, based on the accuracy of the content portrayed in the games. It can be said that the students who made games in the High and Medium categories were able to best grasp the science concepts, but that the students in the Low category missed key concepts that allowed them to develop a more meaningful understanding of their topic. The students of the three games in the Low category still showed growth in understanding during the three points of assessment, but their understanding did not fully develop. Perhaps if these students had been given more iterations of the design cycle to ask questions and to interact with the science topic and the game, there would have been more time to build a more meaningful understanding.

The process of making a video game helped students articulate their understanding of the science topic. According to Kafai (1995), designing games “puts students in charge and engages them in a continuous dialogue with their own ideas” (p. 15). These inner dialogues became vocal when students interacted with peers in the classroom, asked questions in group meetings with the S-SME, explained their games during the final presentation, and they are even expressed in the very game itself. Through this, it has been shown how student ideas progressed over time as they discussed their work. Students were constantly interacting with their game, testing their own ideas and concepts as they worked them into their design. If this was all going on inside the students’ minds, then it was during the weekly meetings with the S-SME where students were finally able to vocalize their work. Students were given a platform to describe their game every week, and as a result, they were discussing their science topic each time as well. When they asked questions about their topic or showed off their game, it was an opportunity for students to explain what they knew, and it gave the S-SME a chance to identify what the students understood about the science in their game and how she could guide them toward filling in the gaps. Similarly, Gallas (1995) said that student understanding of the science concepts were revealed through her elementary classroom science talks.

Having students articulate their understanding of the topics is beneficial not only for teachers (in this case, the S-SME) to become aware of what the students know and are thinking about, but it is also beneficial for students as well. Sawyer (2005) maintains that articulating goes hand-in-hand with learning and that at times “learners don’t actually learn something until they start to articulate it” (p. 12). It was important for students in this study to explain their games to the S-SME each week, as it allowed them to think out loud and discuss the topic with an expert. At times, talking about their topic made students realize that they needed to know more. When students arrived at the meetings with questions in hand, it was because they had already recognized there was a gap in their own knowledge, and they needed to discuss their topic with the expert. This is a consistent finding with a precluding research study (Khalili et al., 2011). However, is not enough for students to simply articulate what they know, their explanations need to be scaffolded if they are going to be effective toward learning (Sawyer, 2005). Indeed, prior research studies show that students who are communicating and reflecting upon science topics need guidance and scaffolding to build a better understanding of the topic (Bell & Linn, 2000; Davis, 2003). This is the role the S-SME took on in this study, to help scaffold students’ understanding of the science topic as they approached her with questions and explanations so they could build richer concepts of the topics and articulate what they knew. In fact, during the *discuss* stage of the reflect-design-test-discuss, students used this time specifically to discuss their projects with the scientist every week, allowing them the opportunity for articulation.

As students articulated their understanding of the science topics from week to week, it revealed the conceptual changes that were occurring with respect to their topics. Conceptual change refers to how students build their knowledge based in new ideas while situated in the context of the old ideas (diSessa, 2005). While there are many different conceptual change learning approaches, this study looks to the works of conceptual change based on assimilation and accommodation. Posner, Strike, Hewson, and Gertzog (1982) assert that there are four conditions for the accommodation of conceptual change: dissatisfaction, intelligibility, plausibility, and fruitfulness. In dissatisfaction, the learner must find that there is something wrong with the current way of thinking that does not fit to help to solve the current problem. Intelligibility refers to the learner being able to make sense of the new concept, and perhaps this is made clear to the learner through example and analogies. Plausibility must show to the learner that the new concept is able to solve the current problem better than the old concept. Fruitfulness refers to the new concept opening up new avenues of inquiry for the learner. These four conditions can be found throughout the iterative processes of designing games and thinking about the science content. Students would enter the meetings with the S-SME with questions that had brought them to a state of dissatisfaction with their current understanding of the concept, such as when Michael came into the meeting wanting to have an enemy for his neurotransmitter game, but realized that this did not make sense for neurotransmitters. The state of dissatisfaction was revealed when students realized the gaps in their own knowledge, that what they currently knew about the science topic was not adequate—gaps that were sometimes revealed when they tried to articulate their understanding, and found they could not. The condition of intelligibility came about during and after S-SME meetings, through discussions provided by the S-SME and the period after when students had to make sense of the new information into their thinking and their games. Plausibility occurred when students decided to use the new information for the current understanding of the topic, that they could understand the concept better and as a result, it would be incorporated into their games. Fruitfulness came about when students began to use their new foundations of the science topic to continue to think in new avenues, such as the students in Group-2 who worked on the myelin sheath topic and then decided to discover what causes the deterioration of the myelin.

These conceptual changes that students experienced provided insight into the progression of their understanding of the science topics during the game design workshop. The conceptual changes could not have occurred without the opportunity for students to articulate and explain their projects, which helped both the students and the S-SME identify their issues or their next pursuits. These changes also could not have been identified if not for being able to follow the students own words about their understanding.

Although the students of 9 out of 12 games were shown to have been able to successfully articulate their understanding of their science topic by the end of the game design workshop, not all students in this study were able to do this well. The students who created the three games in the Low group had the most trouble with understanding—and communicating this understanding of—their topics. James, who created a game about the myelin sheath, was driven more by making an exciting game than staying true to the topic, and although he showed an improved understanding of the myelin sheath over the first weeks of the program, his need to add obstacles to his game ultimately added additional features to his game that did not make sense in relation to his topic. Anthony created a game about gene regulation, but he was more interested in bacteria and ultimately incorrectly made connections between the role of bacteria and viruses with respect to his topic. For these two students, conflicting ideas they had could not be reconciled with their topic to make a cohesive game. The four students who created the last game in the Low group had a different dilemma. Their topic was about signal integration and it was arguably a harder concept to follow than the other three topics (although this one group was the only one to pick the topic, so there is no other comparison to another game). The group also had issues collaborating together in order to create the game, which led to missed opportunities to engage with their science topic. After multiple discussions with the S-SME, they seemed to start to have an idea to work with in the very final week of design, but it was too late to make a coherent game and they could not clearly articulate what was happening in their game in relation to their topic.

Student Attitudes

RQ2a: How Does the Game Design Experience Affect Student Attitudes Toward Science?

In creating a learning environment for students to design games about science, one of the goals was to increase interest in the field of science and technology. Thus, I wanted to see if working with a science topic by way of making games could improve attitudes and generate interest in science. For this task, the TOSRA (Fraser, 1981) attitudes test was used, as it had it been used reliably before, had the subscales relating to attitudes and interest in science, and was appropriate for the age of the students in the game design workshop. Students were given the surveys at the beginning and end of the workshop, within a 3.5-week period of time. Results did not show any statistical significance on the questions pertaining to Adoption of Scientific Attitudes, Enjoyment of Science Lessons, or Career Interest in Science. However, the means of each scale indicate there was improvement in responses from pre- to post-survey in each category, with the most significant improvement belonging to Career Interest in Science.

Although the TOSRA questionnaire has been shown to be reliable for science research studies, it may have been out of place in using it with science learning in a game design environment. My hope was to use the scales to bridge the science in classrooms with science as it was being discussed and developed in their games, but I do not believe this happened. For example, some items on the questionnaire include “Science lessons bore me” or “School should have more science lessons each week” but these connections to classroom science lessons and school may not have been even thought about during the game design workshop, as it was not in a classroom school setting. As such, it would be a service for future research to design a questionnaire to have students think about their attitudes toward science that are not directly related to school, laboratories, or classrooms.

A more interesting survey about thinking about science was created by the S-SME and distributed to students at the same time as the TOSRA. Students were given five diagrams to examine and respond to “I would be able to understand this diagram if I read it and thought about it” in according with to a 5-point scale from “I agree definitely” to “I disagree definitely” (See Appendix A). These diagrams included images of processes that would not have yet been taught to the students, and only one of them had vocabulary that was mentioned during the game design workshop. There was no statistical significance to the results from pre- to post-survey, but all students showed marked improvement in responding to the question.

Verbal feedback from students indicated that the game design workshop was an enjoyable experience for them and that they enjoyed making their games about science. This is promising for creating positive experiences for students with science-related projects.

RQ2b: How Does the Game Design Experience Affect Student Attitudes Toward Making Video Games?

In addition to surveys on science attitudes, students were given a questionnaire about attitudes toward making video games, based on a modified version of the Intrinsic Motivational Inquiry instrument (Deci et al., 1994). Of the 12 questions, 2 showed to have statistical significance with respect to $p \leq 0.5$, “I am pretty skilled at making video games” ($M1 = 4.63$, $M2 = 5.25$) and “I think I am pretty good at making video games” ($M1 = 4.88$, $M2 = 5.25$). These indicators were both under the scale of Perceived Competence. It is encouraging to see that students felt better about the ability to make games after their experience in the game design workshop. This echoes students’ sentiments in their interviews that they enjoyed making their science games.

Another change from pre- to post-survey was that students indicated that they enjoyed making video games about Science and Sports the most. These results were statistically significant (Science, $p = .017$, Sports, $p = .012$). An interesting aspect here is that in the pre-survey every single student put down the same number for every subject that was listed on the survey: They did not each give the same number for each item, but students picked one score from 7 (“Very True”) to 1 (“Not True At All”) and used that across the board. One might expect a few students to do this if they wanted to quickly get through a section, but all 16 students did this for the pre-survey, each with a different weight. This may indicate that at the beginning of the game design workshop, before any topics were introduced, students did not much care or even think about any subjects that they could make a game about. However, after the post-survey, none of the students did the same procedure of giving one score for all subjects; they actually took the time to rank them. As Science was picked as one of the subjects highlighted by students that they would enjoy making games about, it gives further credence that they were interested in and enjoyed making games about their science topic.

Limitations of the Study

In this study of student-designed video games, all of the students created their games with the software Game Maker. It was a cognitive tool that aided them because it took away the need to learn every component of game creation, including programming and graphical design, and allowed them to produce their work with relative speed. However, by confining students to this platform, it may have also limited the way students thought about their ideas and created their final projects. As has been shown in this study, students created their games based on games they had already played. Yet, using Game Maker may have narrowed this category further by pushing it into games they had played which they believed could be created on this platform. There is evidence of at least one student, David, who came up with an initial idea for a game in a 3D environment, which he later abandoned when he realized that the platform only supported 2D environments.

Another limitation of this study is that its relatively small sample size of 16 students does not lend itself well toward analyzing the quantitative data collected through the surveys. However, as this was a mixed methods study, the data was used to give more insight into the students of this specific game design workshop rather than to make a broad statement about attitudes toward science and technology as a whole.

Additionally, I believe a further limitation of this study is the unevenness of having one group of four students form to make a game when most of the other students created single games, or in the other case, formed a group of two. Based on a successful pilot study where students formed into groups of four to create science games (Khalili et al., 2011), I believed that the students who asked to join together would be able to do this as well. However, because there was only one large group, time was not spent to make sure the group was able to communicate and organize themselves before starting into their game design. Despite their enthusiasm for the project, the group was often disorganized and could not communicate their ideas effectively. All the students were bright and interested in the project and I believe they would have all fared better working on single games.

Implications of the Findings

The research study reported on student strategies during the design process, student understanding while learning about their science topics, and student attitudes toward science and making video games. The implications for the strategies that students were found to have used in the game design workshop will be highlighted under Students Making Games. The implications of the findings about student understanding will be discussed under Designing Games With Science. The results of the student attitude surveys will be further explored under STEM Learning.

Students Making Games

This study created an open-ended constructivist learning environment (CLE) for students to explore the constructionist activities of designing video games about science topics. With tools and support made available for students in a CLE (Jonassen, 1999), the strategies used to create the games were observed. One of the strategies students used to make their games was to base them on games they had already played. They needed something familiar (a known game) to help them define the unfamiliar (science topic). Kafai (1995) sees this as a form of problem-solving, and indeed, this strategy may have made it easier for students who not only had to explore their science topics, but also had to figure out a way to convey the topic through a game. Baytak (2009) points out that if this is the case, then students should be exposed to different games and platforms, to allow for them to have more of a foundation to choose from. However, as the focus in this study was to make a game based on a science topic, it would be beneficial for students to also experience educational games, such as the science game Immune Attack, which traverses inside the human body and provides realistic information. Playing a game like Immune Attack before embarking on the design of their own games may have given students another related case to pull from when considering their own designs, especially as it combines a method of game play and accurate information. It would be important to expose them to more than just one educational game, however, to prevent students from trying to imitate just one game. Additionally, as students may be influenced by their existing knowledge structures of what makes up entertaining games, it would be helpful to have other activities besides just video games to stimulate student ideas. This could include other educational media outlets, such as television programs, or hands-on classroom activities.

With respect to the resources students used to supplement their knowledge when the scientist was not available, students gathered information on their topic by using notes they had collected in their Game Design Journals and by conducting web searches. The activity surrounding the web searches is interesting to note, because it is a similar problem as gathering information for a research paper: Is the information on the web suitable and reliable? This is a problem in classrooms that is separate from video game design (Schofield, 2005). Students were given the approval to use websites like Wikipedia as a starting point for research, but were encouraged to use trusted websites that were provided to verify the information. As this proved difficult to do on their own, students brought their findings to the S-SME to validate, or else they could verify them together. This highlights the need for proper support for students gathering information on the Internet in any setting, whether for making games or for writing reports. Having the S-SME for student support was very important.

This need for information also highlights how important it is to make resources available for students that they are able use effectively, otherwise they will resort to relying solely on websites such as Wikipedia. Thus, it is equally important to check in with students and monitor how they are using their resources and if the resources are appropriate.

Another component of the design process that helped students with their games was the collaborative processes they experienced in the game design workshop. Although most students in this study chose to create a game individually, they were still interacting with their peers in the computer lab. This was due in part to the proximity of the computers in the lab—students were able to walk around freely to one another's computers and interact; they were also able to see many screens and other students' work from their own workstations. This is also due to the nature of the artifacts they were working on; making games requires that their creators play the games to test them out, inviting others to watch and ask to play the games themselves. Thus, to encourage and foster these types of collaborative interactions, the setup of the work environment is vital, to keep students close to each other and able to walk around and interact. To continue the spirit of collaboration among students, it would be beneficial to encourage student testing of each other's games, and to allow for time for students to present and share their games to their peers at regular intervals during the game design workshop, or class. In this workshop, students presented their work only at the end, which was a great way to share knowledge and receive feedback from the crowd, something students would have undoubtedly benefited from if it had happened more frequently.

However, in this study, one group could not collaborate successfully to produce a cohesive final product. Group-4 did not take the time to plan together before they broke off into individual pieces of the project, which did not allow for their separate pieces to fit together, especially as they were unaware of what the other members were working on. In this scenario, more support should have been offered to help the group work together. Indeed, what was made clear in this study is that the support offered for individuals making games is different than for a large group making a game. When an individual creates a game, he or she is the only one constantly interacting with the problem and design, and can try to identify issues and problems that need to be worked on. With a group, because there are multiple students working together for one common goal, it is vital that they understand how to communicate and negotiate the problem together, distribute tasks and responsibility, and help each other problem-solve. A better approach would have been to help them organize themselves to a point where they first agreed on a game design before taking on separate roles in their group, where they could then work together for a common goal. This reveals that collaboration between group members requires more support in order for each member to benefit from and contribute to making a game.

Designing Games About Science

The game design workshop allowed students to explore their understanding of science topics through making games, thereby creating artifacts that expressed their understanding of their topics. In observing the students’ design process and artifacts, this allows for some insights about game design about science topics.

The iterative cycle of design allows for students to reflect upon their topics, create and test their games, and discuss the game and content in order to gain more information to continue the cycle again. The *discuss* stage with the S-SME is a driving force to propel students into this cycle of thinking about their science topics. When students entered this stage, they may have already come to a point of dissatisfaction or confusion with the topic, which they would discuss with the S-SME to clear up, or they came in with prototypes of their games to explain. This opportunity for explanation of their confusion or their work allows for a chance for students to articulate their understanding of the science up to that point, a way for them to think out loud (Sawyer, 2005). This provides insight to both the student and the S-SME about what gaps in the knowledge exist, and the S-SME guides the student into a discussion where he or she is able to take new information away from this meeting to reflect upon. This information may help change the ideas and concepts in the student's mind, which then finds its way into the game.

However, making games may also limit the scope of content exploration. As seen with the students in this study, they chose to create games based on games they already know, using the mechanisms inherent in the games (such as destroying enemies and surpassing obstacles) to help them make sense of the science topics. For the purposes of this study, this was a valid and interesting find, that almost all students used this strategy in order to help them understand the science topic. It has been demonstrated in the literature about learning science that students use old ideas to make sense of new ideas (diSessa, 2005; diSessa & Sherin, 1998; Posner et al., 1982). diSessa and Sherin (1998) in particular discuss how concepts, or a coordinated classes of concepts, are established by integrating the relevant information needed from current observations and making sure that multiple observations continue to make sense for that context. They also discuss the casual net, which is the “general class of knowledge and reasoning strategies that determines when and how some observations are related to the information at issue” (p. 1176). However, if students are using their existing notions of game schema to guide them toward understanding science, the familiar game ideas may have blocked opportunities for more authentic learning. What else would students be capable of thinking about in terms of their topics, if they did not feel the need to create challenges and win-states in their video games? The very strategies students used in order to relate to the science could have held them back from deeper understanding.

Thus, there are advantages and disadvantages to creating video games about science. It is a way to engage students in a design process that helps them shape their understanding of the topic. It is a way to expose students to the fields of science and technology and hopefully create a positive learning experience that will encourage them toward these subjects. Yet, the very creation of the game may limit the scope to which students set out to explore their topics.

STEM Learning

This study wanted to see if participating in the game design workshop affected student attitudes toward science and technology, in order to see if they could be encouraged toward these fields. Students were given pre- and post-surveys of a modified version of the TOSRA (Fraser, 1981) to determine attitude changes about science attitudes, enjoyment of science, and career interest. Although results were not statistically significant, student means did slightly increase over time, with the highest improvement in career interest. Additionally, although not statistically significant, students improved on their perceived ability to look at and interpret diagrams on scientific processes, as provided by the S-SME.

Students were also given a pre- and post-survey on a modified version of the IMI instrument (Deci et al., 1994) to determine attitudes toward making video games. Student attitudes toward their ability to make video games did increase, with statistical significance, as well as their enjoyment of making video games about science. The game design workshop seems to have had a positive effect on students' perceived ability and confidence in making video games.

Confidence in science and technology is step toward preparing students for careers in science, technology, engineering, and math (STEM). DeJarnette (2012) proposes that in order to have students interested and motivated in STEM careers, they need early exposure to STEM activities such as in workshops and camps, much like the game design workshop in this study. The increased interest in STEM comes from a national objective to make sure the United States does not lag behind in fields of science and technology (Atkinson et al., 2007; National Academy of Science et al., 2010). This focus for preparing kids for STEM careers should then be to prepare them for "thinking critically and making judgments," "solving complex, multidisciplinary, open-ended problems," "communicating and collaborating," and "making innovative use of knowledge, information and opportunities" (Partnership for 21st Century Skills, 2008). These are the very skills students are engaging in while making their science games in a game design workshop. Kafai and Peppler (2012) state that participating in game design programs gives students experiences very similar to that of game design professionals, giving them exposure to field that relies on these very STEM skills. In fact, Resnick and Rosenbaum (2013) say that the “tinkering” that can comes about with design, especially design to make games, can fit well into STEM goals and in fact encourage students toward these subjects who may normally be “turned off” by math and science. In this study, it has been shown that students making video games on science topics not only gain technology skills through the game design software and are exposed to science in a new way, but they also develop strategies for learning, communicating, and understanding new information. It is the hope of this study that this exposure continues to fuel their interests and not only propels them toward science and technology fields, but encourages new ways of building knowledge in the world.

Future Work

Students making games is a concept that was introduced by Seymour Papert (1980) and his idea that children could build their own knowledge by programming in LOGO. Since then, technology has advanced and students are now capable of making more complex and professional-looking games with the aid of game making software such as Game Maker and Scratch. This has no doubt been a benefit to game making research studies, giving learners an easier introduction to programming and game design. Yet, even with the advances in and availability of technology, Resnick (2012) claims there has still not been a shift that takes children into the heart of designing and creating with computers.

Thus, the future of students making video games is wide open with potential. A natural extension of this study would be to design a science lesson or research unit with game design to see how it measures against a true science classroom's lessons. Although students making games have been studied in real science classrooms (Ching, 2000; Kafai & Welsh, 2007; Marshall, 2000), evaluation of any content has happened independently and within the context of the study. It would be interesting to create a study along the lines of Kolodner et al.'s (2003) project-based learning, but in the context of student game design. The study by Kolodner et al. (2003) focused on students not only creating an engineering design model based on science lessons, but also included classroom activities, mini-investigations, collaboration with groups, and sharing projects across groups. This type of study can see how the activities other than video games would be able to lend a pool of rich and valuable resources to stimulate student ideas for their own games. It would be valuable for the field of game design research to see if students could use game design in science classrooms as a viable method for learning content.

Conclusions

The game design environment used in this study was based on a constructivist model (Jonassen, 1999) to provide learner support for students immersed in the constructionist activities of creating video games. As supported by Papert's (1980) notion that learners can build knowledge through artifact creation, students were able to construct and build upon their understanding of immunology science topics through game design. This study showed that students were able to (a) problem-solve by establishing strategies for creating games about science topics that were unfamiliar to them, (b) use tools for reflection and design, (c) engage in collaborative interactions, (d) research and engage in discussions with a science expert, (e) be involved in changing their understanding of the topics, including identifying what they needed to know and understanding that they did not know enough, (f) articulate their understanding, and (g) create an artifact representing their knowledge.

This iterative cycle of game design provided opportunities for students to engage with the science content by thinking and reflecting about the topic, designing the content into the game, articulating their understanding in their own words, and through discussions with the S-SME when they were gaining new information to take back to reflect upon, ready to start the cycle again. In this way, the students are thinking about the science in an iterative cycle alongside designing the physical game, and their understanding of the topic is being shaped through the iterations.

Therefore, students are not just concerned with the technical aspects of the game, but with the creative aspect of incorporating the content into the game, and in terms of educational content, providing accuracy for the content as well. Thus, as students enter one or more stages of the cycle, they are reconciling these elements at the same time, especially if one or more elements (e.g. new content information) needs to be accommodated. It is a form of problem-solving and critical thinking, and requires that students are always aware of how to make all the pieces of their project come together. These skills can be valuable to students in terms of preparing them for STEM-oriented fields.

Indeed, it is hoped that students participating in a game design environment may be further encouraged toward the fields of science and technology. Whether designing these games about science can help students further understand the topics, particularly in relation to learning science in a classroom, is a matter to be looked into for future work. Based on the experiences of the students in this study, designing science games is an enjoyable experience, exposes them to science, and helps them think about and articulate what they are learning. This is encouraging for increasing STEM interest and knowledge.

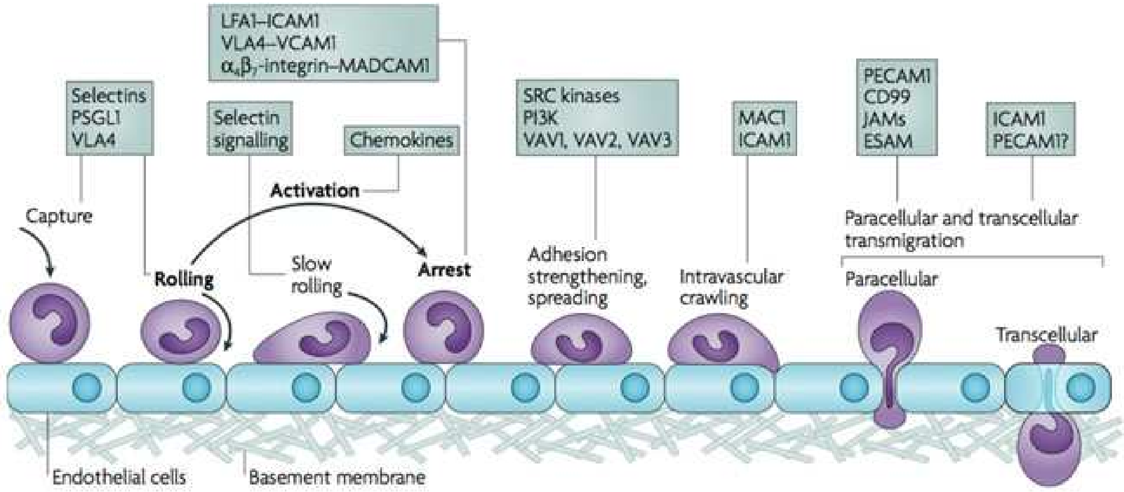
APPENDIX A. SURVEYS

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
I enjoy reading about things which disagree with my previous ideas.	5	4	3	2	1
Science lessons are fun.	5	4	3	2	1
I would dislike being a scientist after I leave school.	5	4	3	2	1
I dislike repeating experiments to check that I get the same results.	5	4	3	2	1
I dislike science lessons.	5	4	3	2	1
When I leave school, I would like to work with people who make discoveries in science.	5	4	3	2	1
I am curious about the world in which we live.	5	4	3	2	1
School should have more science lessons each week.	5	4	3	2	1
I would dislike a job in a science laboratory after I leave school.	5	4	3	2	1
Finding out about new things is unimportant.	5	4	3	2	1
Science lessons bore me.	5	4	3	2	1

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree
Working in a science laboratory would be an interesting way to earn a living.	5	4	3	2	1
I like to listen to people whose opinions are different from mine.	5	4	3	2	1
Science is one of the most interesting school subjects.	5	4	3	2	1
A career in science would be dull and boring.	5	4	3	2	1
I find it boring to hear about new ideas.	5	4	3	2	1
Science lessons are a waste of time.	5	4	3	2	1
I would like to teach science when I leave school.	5	4	3	2	1
In science experiments, I like to use new methods which I have not used before.	5	4	3	2	1
I really enjoy going to science lessons.	5	4	3	2	1
A job as a scientist would be boring.	5	4	3	2	1
I am unwilling to change my ideas when evidence shows that the ideas are poor.	5	4	3	2	1
The material covered in science lessons is uninteresting.	5	4	3	2	1
A job as a scientist would be interesting.	5	4	3	2	1
In science experiments, I report unexpected results as well as expected ones.	5	4	3	2	1
I look forward to science lessons.	5	4	3	2	1

Statement	**Strongly Agree**	**Agree**	**Not Sure**	**Disagree**	**Strongly Disagree**
I would dislike becoming a scientist because it needs too much education.	5	4	3	2	1
I dislike listening to other people's opinions.	5	4	3	2	1
I would enjoy school more if there were no science lessons.	5	4	3	2	1
I would like to be a scientist when I leave school.	5	4	3	2	1

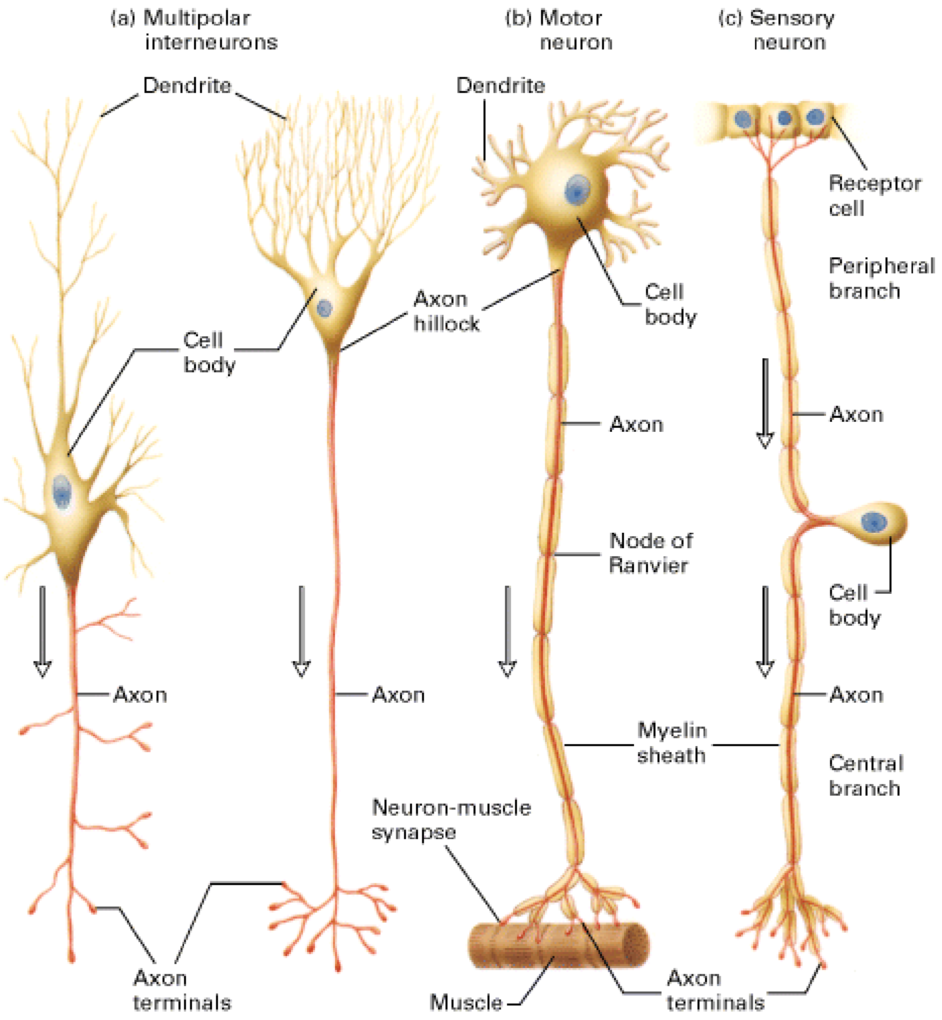
Please look at the following diagram and then answer the question below.



I would be able to understand this diagram if I read it and think about it.

1. I disagree definitely.
2. I disagree somewhat.
3. I am neutral.
4. I agree somewhat.
5. I agree definitely.

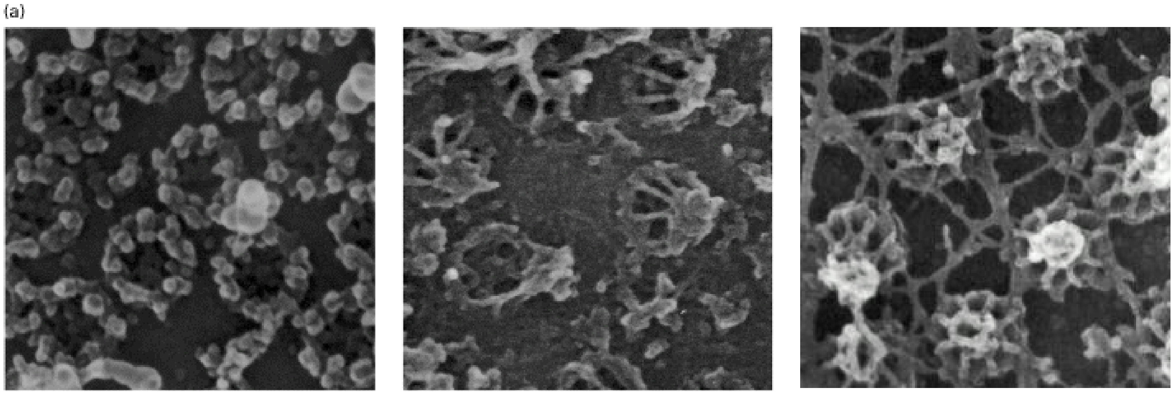
Please look at the following diagram and then answer the question below.



I would be able to understand this diagram if I read it and thought about it.

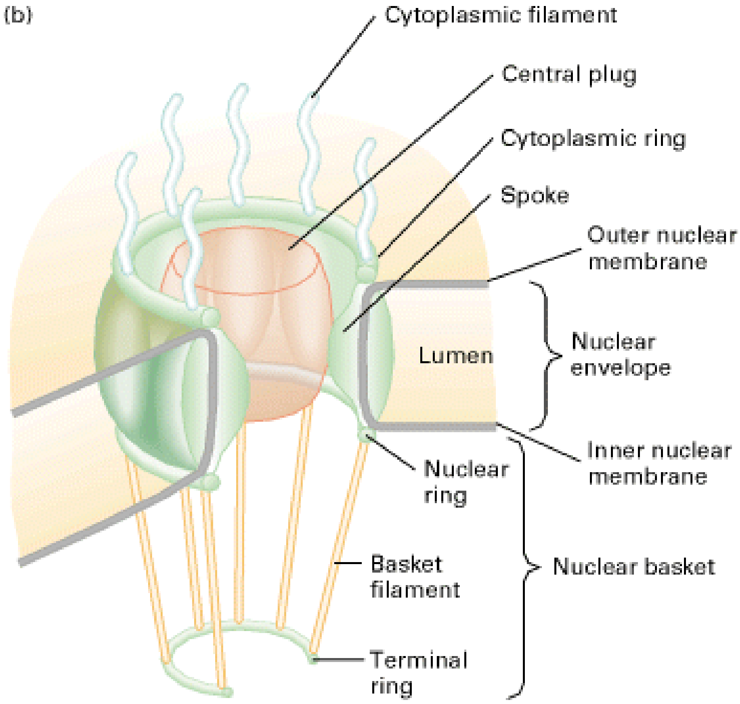
1. I disagree definitely.
2. I disagree somewhat.
3. I am neutral.
4. I agree somewhat.
5. I agree definitely.

Please look at the following diagram and then answer the question below.



I would be able to understand this diagram if I read it and thought about it.

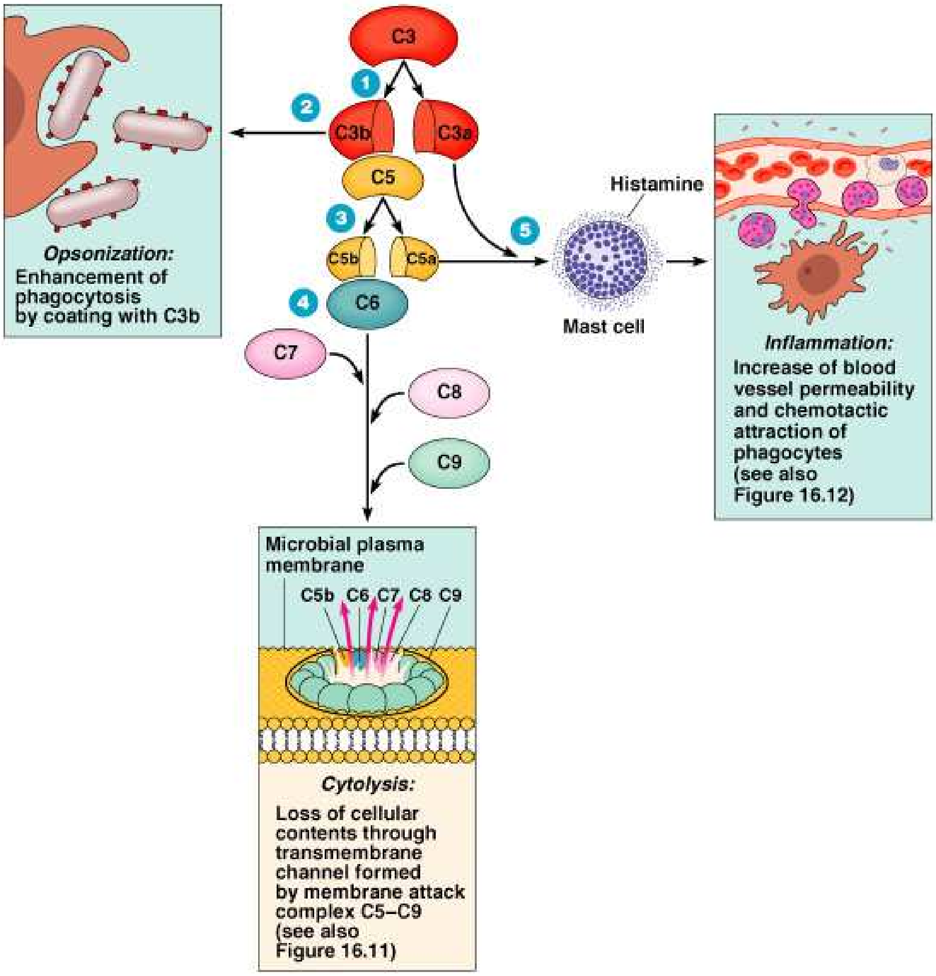
1. I disagree definitely.
2. I disagree somewhat.
3. I am neutral.
4. I agree somewhat.
5. I agree definitely.



I would be able to understand this diagram if I read it and thought about it.

1. I disagree definitely.
2. I disagree somewhat.
3. I am neutral.
4. I agree somewhat.
5. I agree definitely.

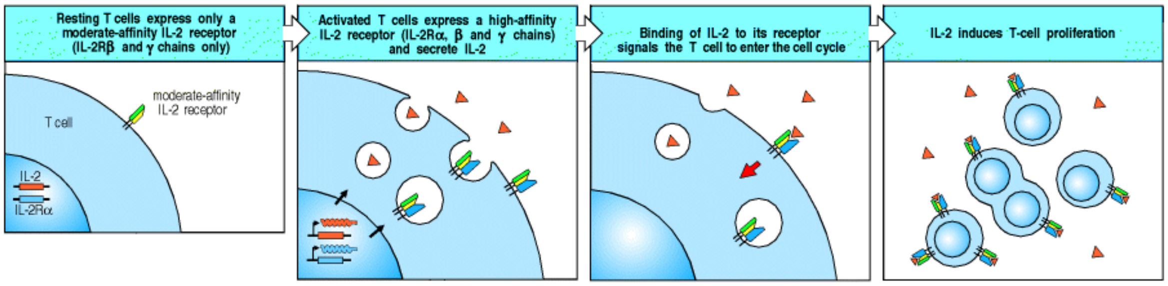
Please look at the following diagram and then answer the question below.



I would be able to understand this diagram if I read it and thought about it.

1. I disagree definitely.
2. I disagree somewhat.
3. I am neutral.
4. I agree somewhat.
5. I agree definitely.

Please look at the following diagram and then answer the question below.



I would be able to understand this diagram if I read it and thought about it.

6. I disagree definitely.
7. I disagree somewhat.
8. I am neutral.
9. I agree somewhat.
10. I agree definitely.

We want to know how you feel about making video games. Please circle the number that shows how you feel about each statement. There are no right or wrong answers.

Statement	**Very True**			**Somewhat True**			**Not At All True**
I enjoy making video games very much.	7	6	5	4	3	2	1
I think I do pretty well at making video games, compared to other students.	7	6	5	4	3	2	1
I believe making video games could be of some value to me.	7	6	5	4	3	2	1
Making video games does not hold my attention at all.	7	6	5	4	3	2	1
I am pretty skilled at making video games.	7	6	5	4	3	2	1
I think making video games is important to do because it can help me get a job.	7	6	5	4	3	2	1
I think making video games is a boring activity.	7	6	5	4	3	2	1
I think I am pretty good at making video games.	7	6	5	4	3	2	1
I think making video games is an important activity.	7	6	5	4	3	2	1
I would describe making video games as very interesting.	7	6	5	4	3	2	1

Statement	Very True			Somewhat True			Not At All True
Making video games is an activity that I can't do very well.	7	6	5	4	3	2	1
Making video games is fun to do.	7	6	5	4	3	2	1

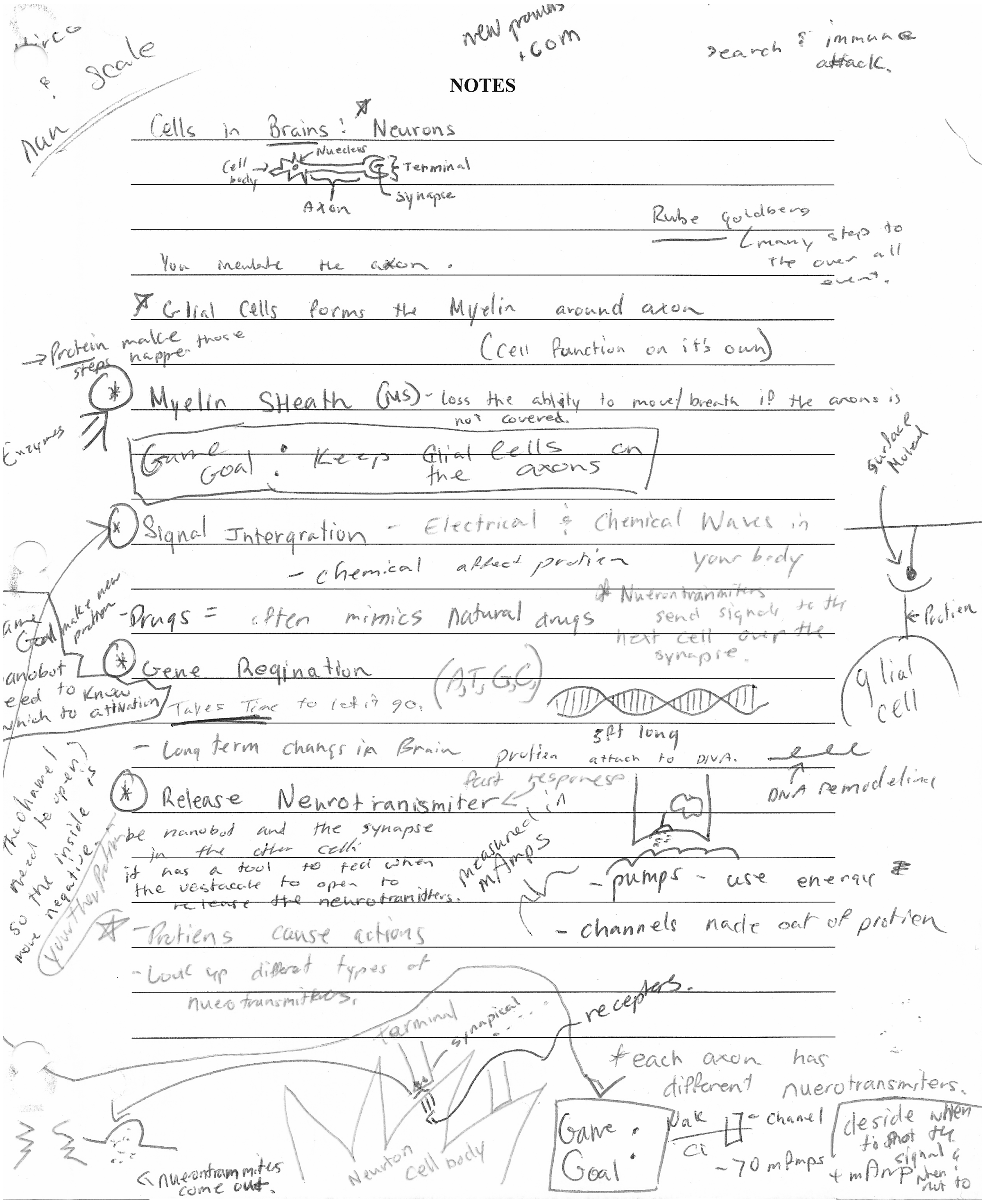
I enjoy making video games about…

Statement	Very True			Somewhat True			Not At All True
History/Social Studies	7	6	5	4	3	2	1
Math	7	6	5	4	3	2	1
English/Language Arts	7	6	5	4	3	2	1
Science	7	6	5	4	3	2	1
Art	7	6	5	4	3	2	1
Foreign Languages	7	6	5	4	3	2	1
Sports	7	6	5	4	3	2	1

APPENDIX B. SEMISTRUCTURED INTERVIEW QUESTIONS

1. What did you think about the program?
2. What was your video game about?
3. Did you like working on your game?
4. How do you think your game turned out?
5. How did you feel about your science topic?
6. What did you do to learn more about your science topic so you could make your game?
7. How did you like working with the science expert?
8. Did you work with any other students on your game?
9. Did you help any other students on their game?
10. Do you think you will show your video game to other people?
11. Would you be interested in designing video games about other science topics?

APPENDIX C. SAMPLE STUDENT NOTES FROM GAME DESIGN JOURNALS



micro & scale

nan

new proteins + com

search & immune attack.

NOTES

Cells in Brains: Neurons

Cell body

Nucleus

Terminal

Axon

Synapse

Rube goldberg

(many steps to the over all event.

You mendate the axon.

Glial Cells forms the Myelin around axon

(Cell Function on it's own)

→ Protein make those steps happen

Myelin SHeath (MS) - loss the ablity to move/breath if the axons is not covered.

Enzymes

Game Goal: Keep Glial cells on the axons

Signal Intergration - Electrical & Chemical Waves in your body

- chemical affect protien

- Drugs = often mimics natural drugs

Nueron tranmiters send signals to the next cell over the synapse.

Game Goal make new protien

nanobot need to know which to ativation

Gene Reqination (A, T, G, C,)

Takes Time to let it go,

- Long term changs in Brain

3ft long

protien attach to DNA.

DNA remodeling

surface Molecul

Protien

glial cell

Release Neurotranismiter

fast responses

measured in mAmps

the nanobot and the synapse in the other cell

it has a tool to feel when the vestacale to open to release the neurotramitters.

the channel need to open so the inside is move negative

your the Path

- pumps - use energy

- channels made out of protien

- Protiens cause actions

- Look up differt types of nueotransmitters.

terminal

synapical

recepters.

*each axon has different nuerotransmiters.

nueorontrammites come out.

Newton

cell body

Game: Goal:

Nak

Cl

Chanel

-70 mAmps

deside when to shot the signal & + mAmp when not to

Figure C1. Sample from Joseph’s Game Design Journal.

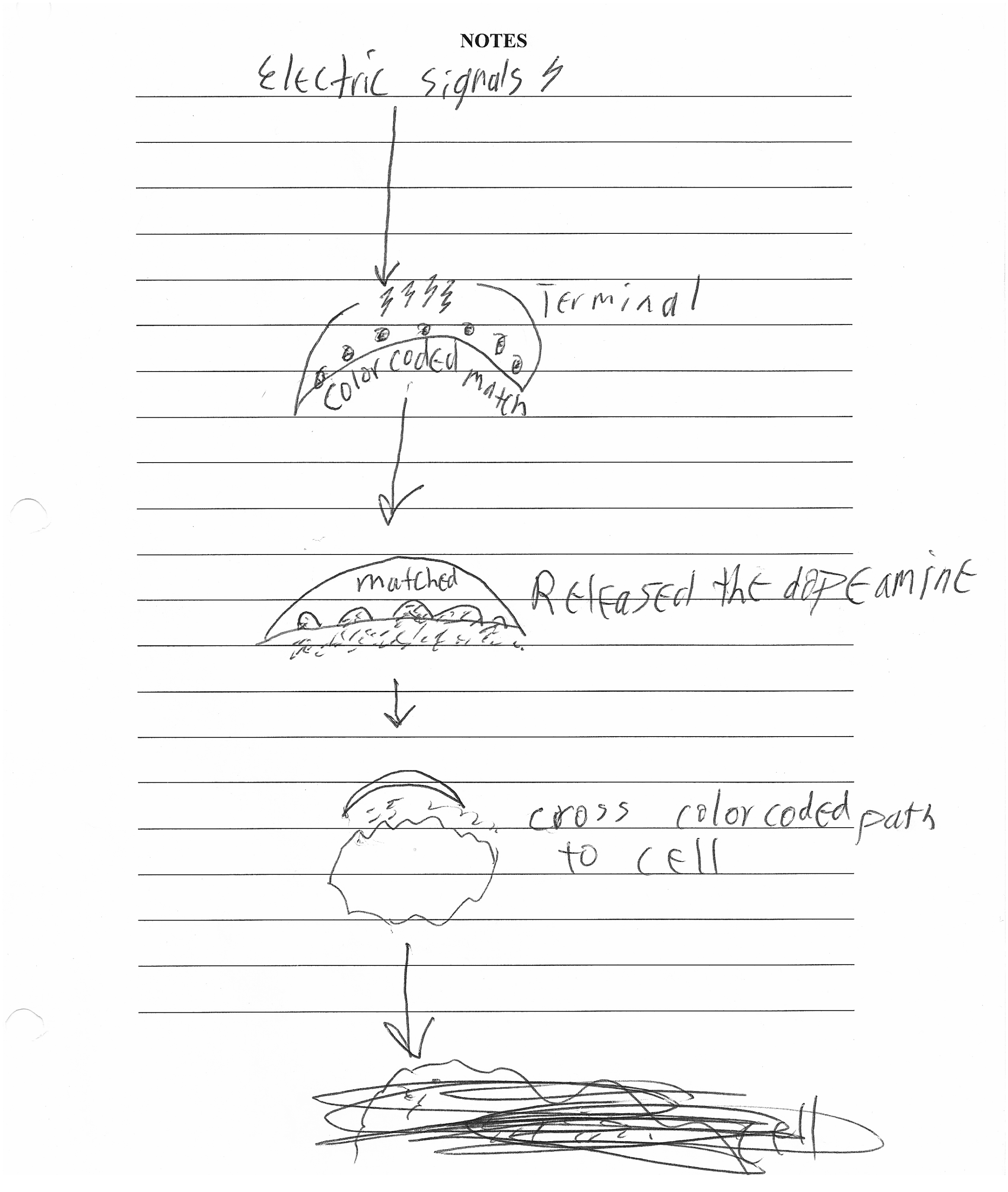
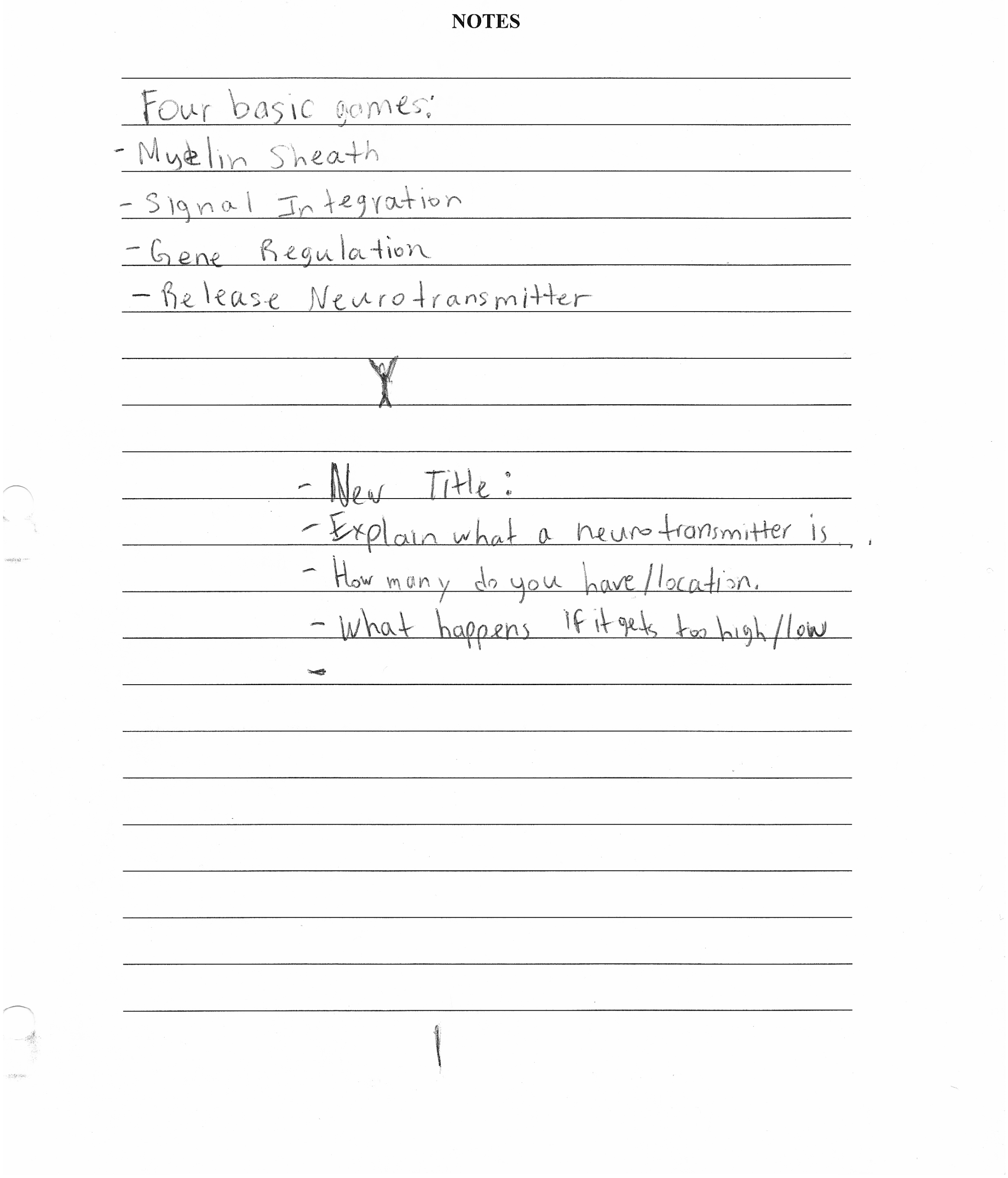


Figure C2. Sample from Dylan’s Game Design Journal.



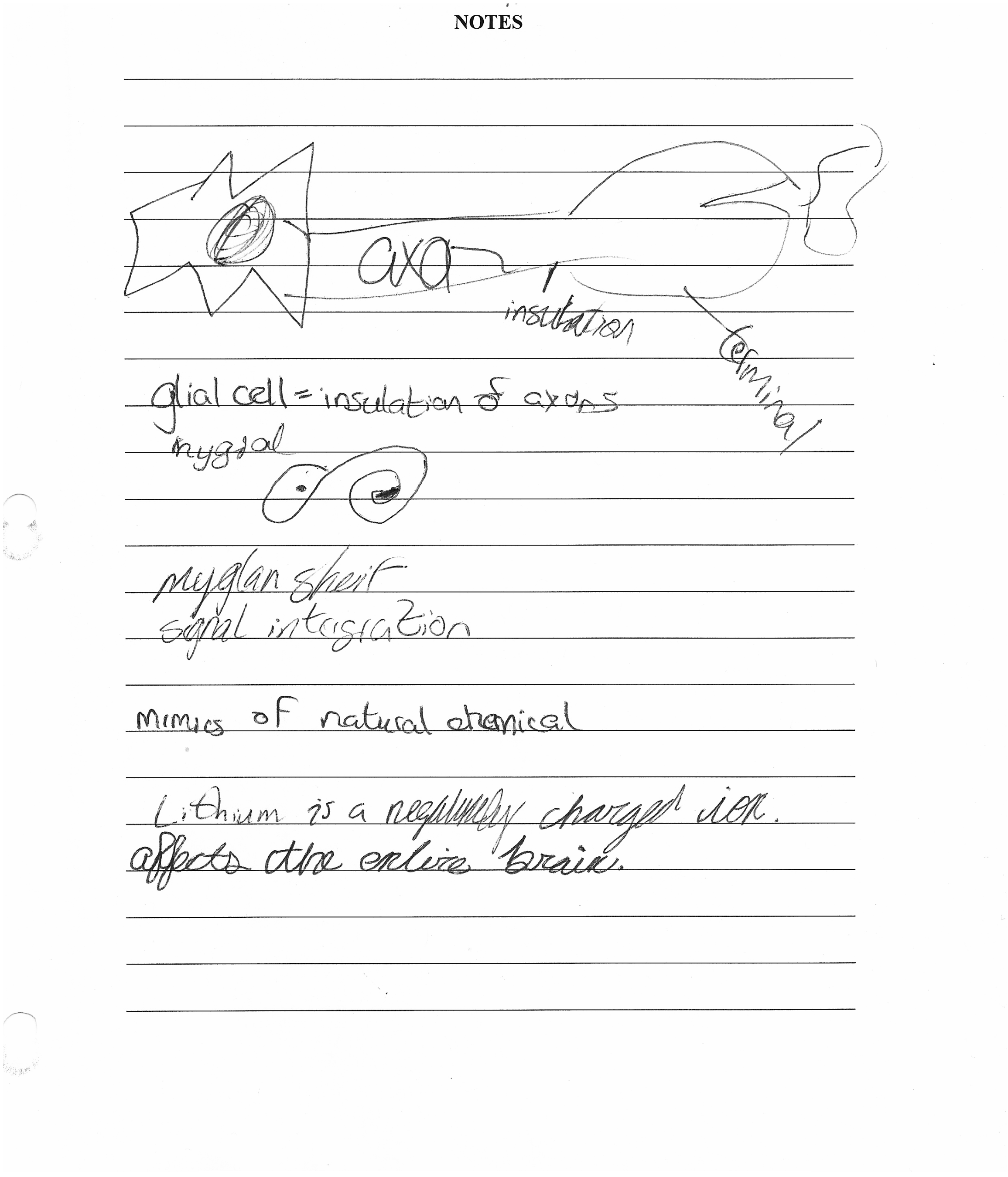
NOTES

Four basic games:

- Myelin Sheath
- Signal Integration
- Gene Regulation
- Release Neurotransmitter

- New Title :
- Explain what a neurotransmitter is .
- How many do you have/location.
- What happens if it gets too high/low
-

Figure C3. Sample from Lawrence's Game Design Journal.



NOTES

axo

insulation

terminal

glial cell = insulation of axons

mygdal

myglan sheit

signal intagration

mimics of natural chemical

Lithium is a negatively charged ion.

affects the entire brain.

Figure C4. Sample from Nick’s Game Design Journal.

APPENDIX D. SKETCHES FROM GAME DESIGN JOURNALS

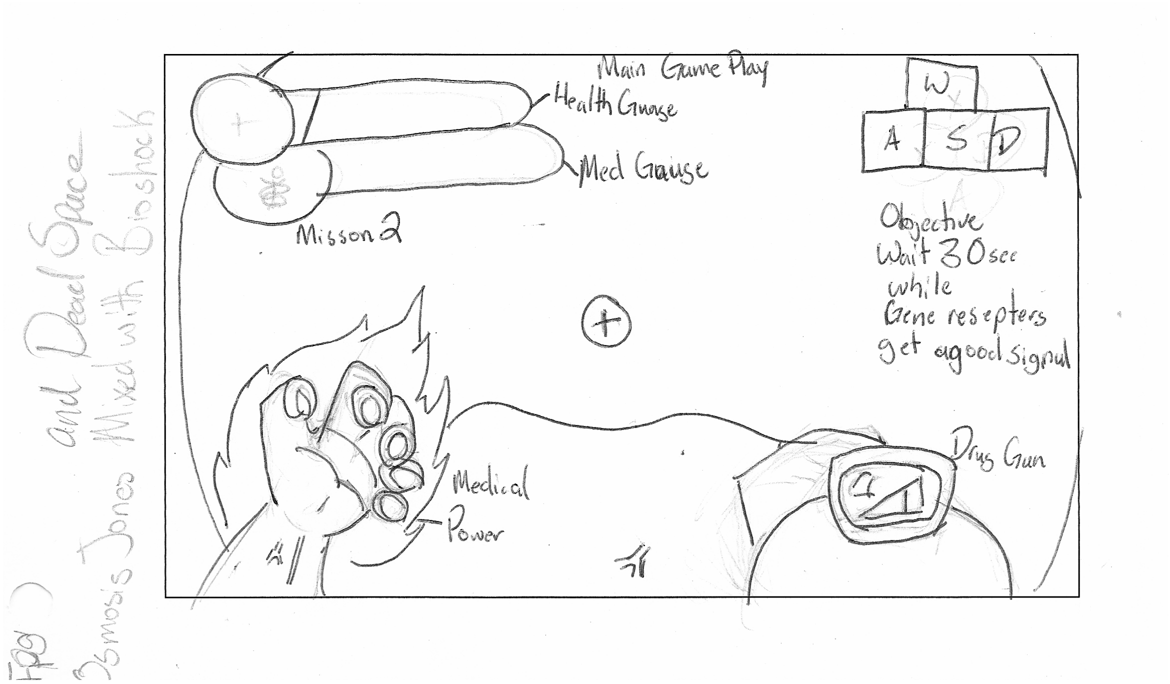


Figure D1. David’s first sketch.

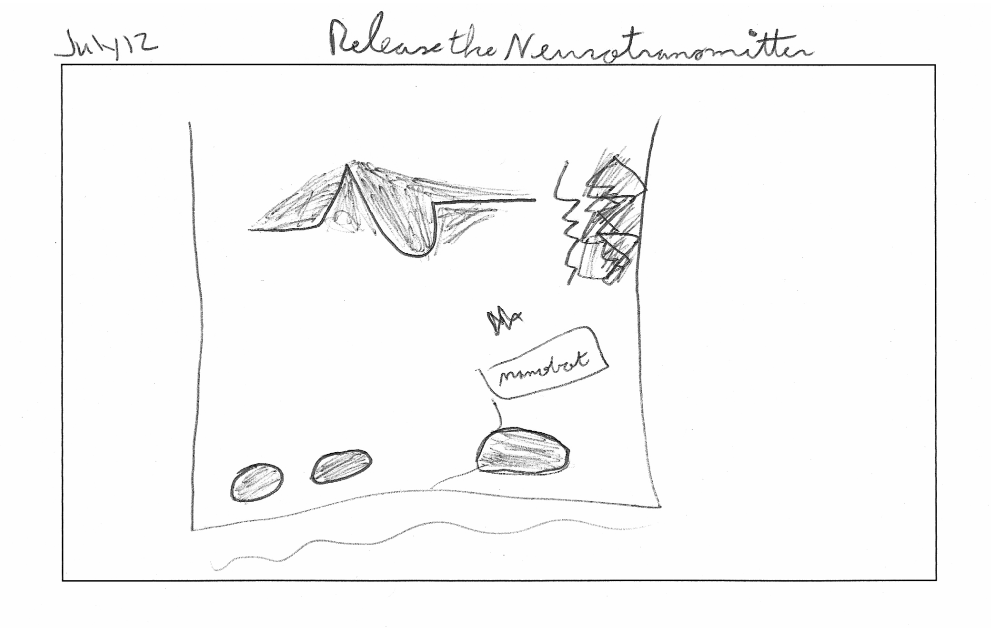


Figure D2. Mark's first sketch.

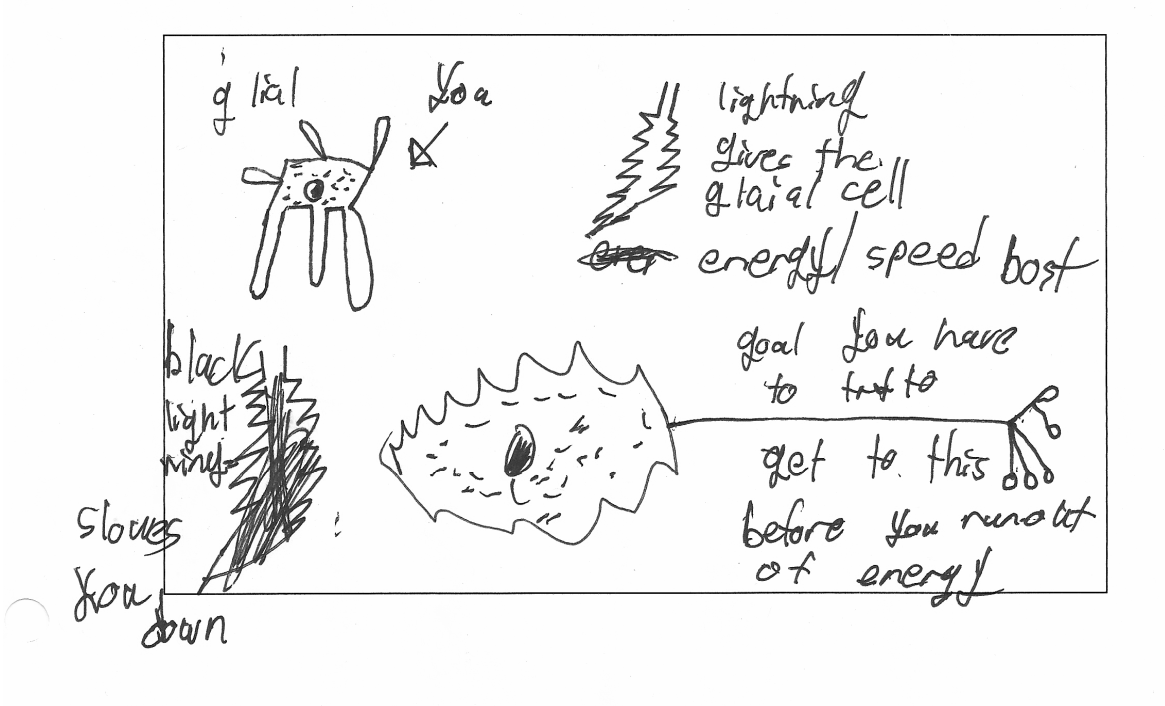


Figure D3. James's first sketch.

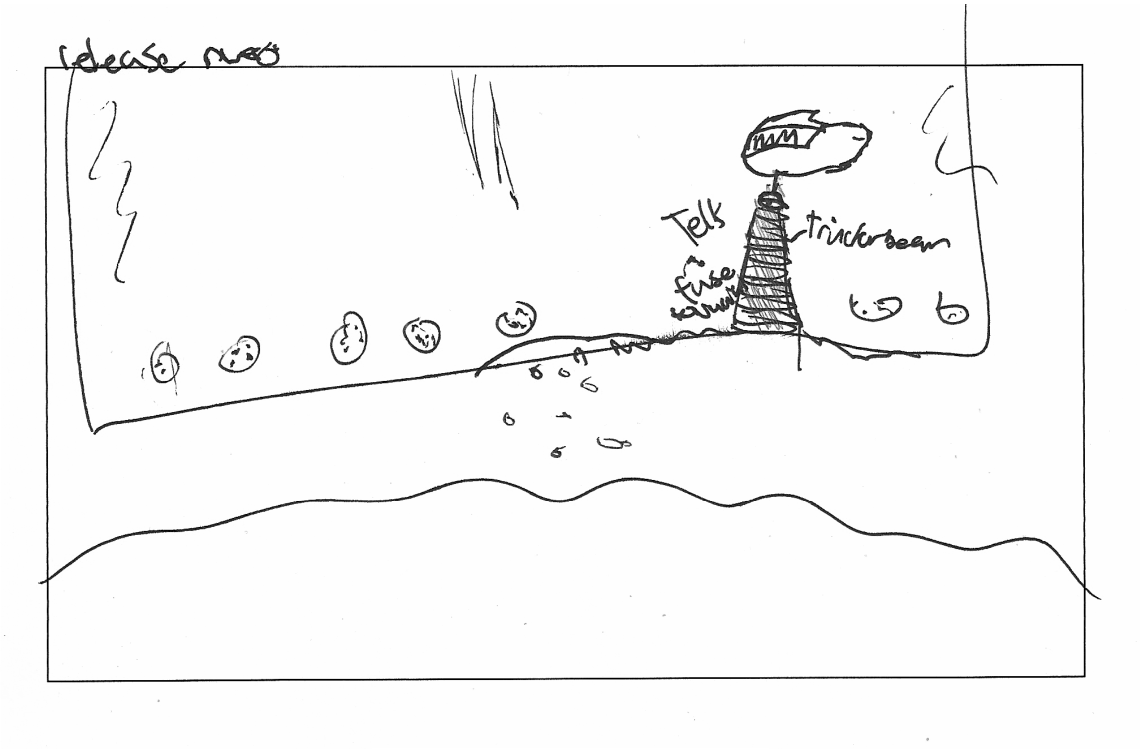


Figure D4. Scott’s first sketch.

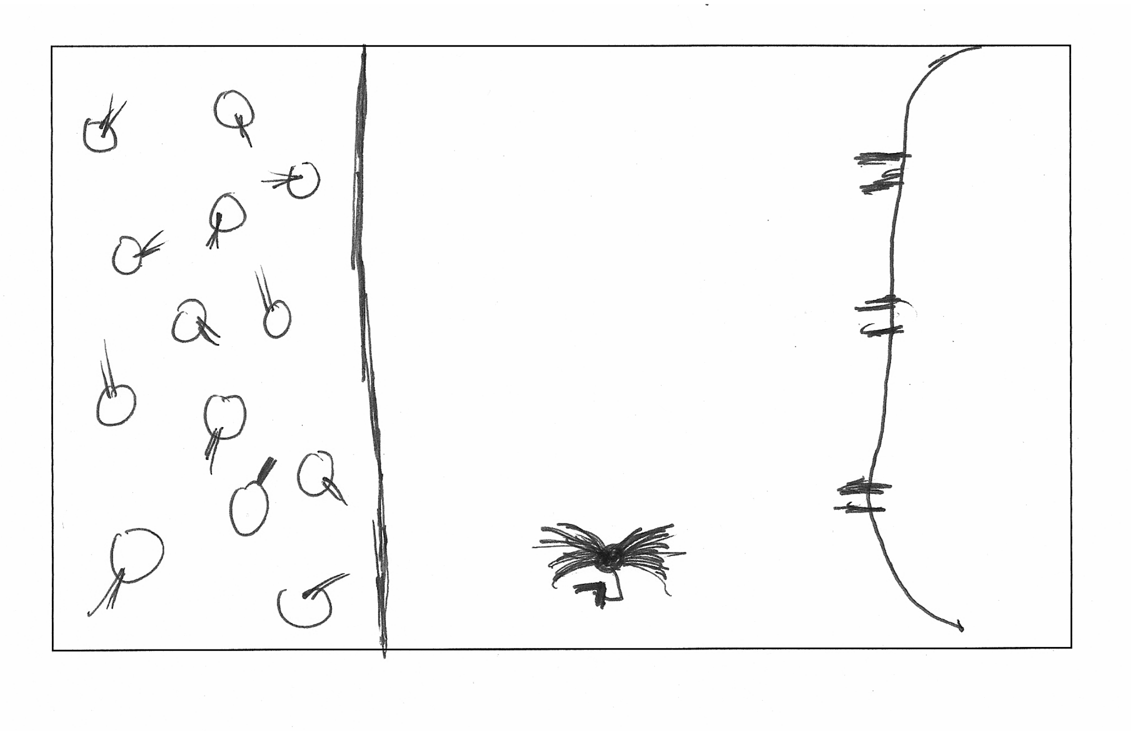


Figure D5. Lawrence’s first sketch.

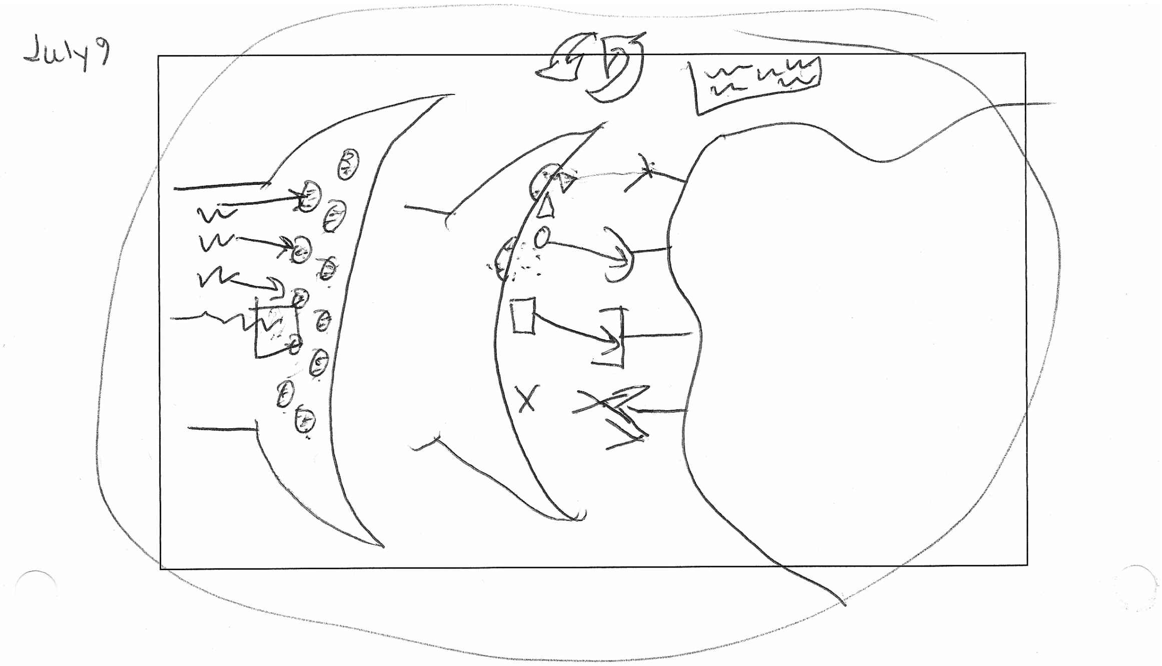
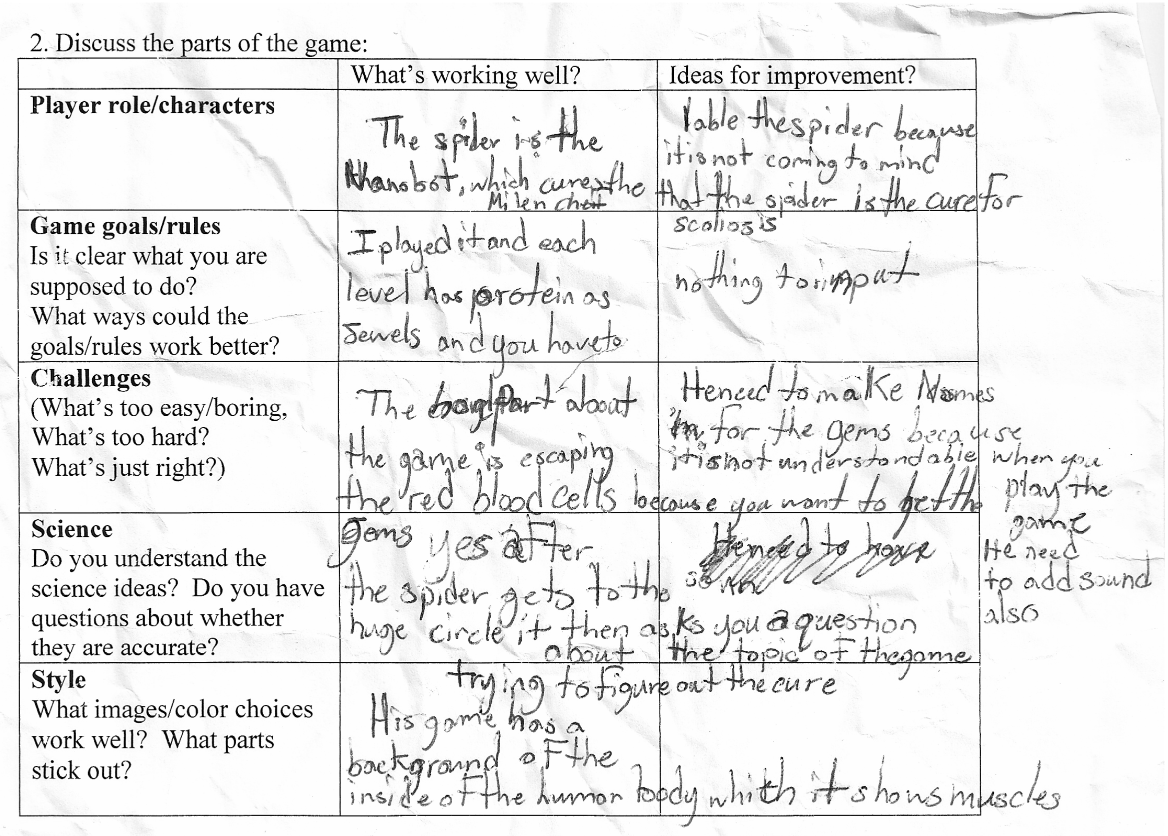


Figure D6. Dylan’s first sketch.

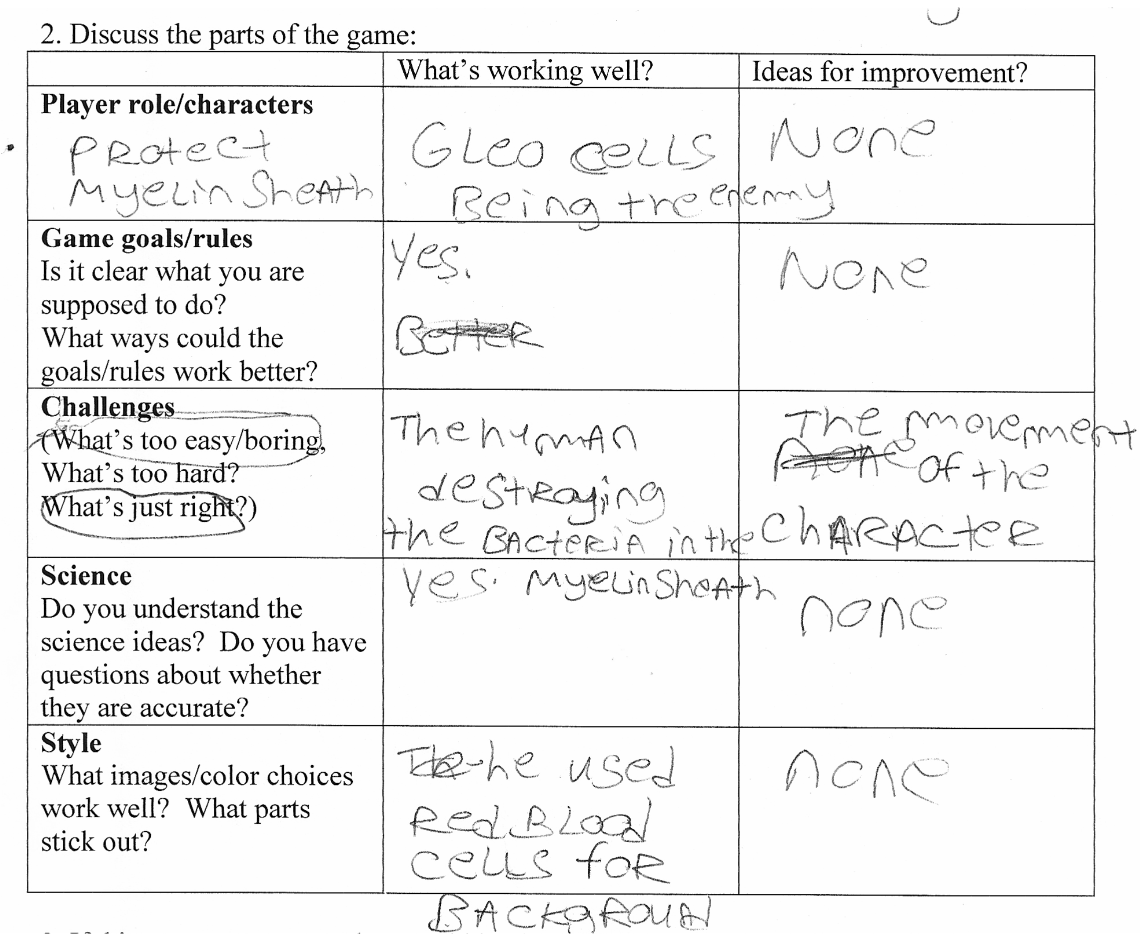
APPENDIX E. PEER MENTOR EVALUATIONS



2. Discuss the parts of the game:

	What's working well?	Ideas for improvement?
Player role/characters	The spider is the Nanobot, which cures the Milen chat	Iable thespider because itis not coming to mind that the spider is the cure for scoliosis
Game goals/rules Is it clear what you are supposed to do? What ways could the goals/rules work better?	Iplayed it and each level has protein as Sewels and you have to	nothing toimput
Challenges (What's too easy/boring, What's too hard? What's just right?)	The ~~bag~~part about the game is escaping the red blood cells because you want to get the gems	Heneed to make Names for the gems because itisnot understandable when you play the game
Science Do you understand the science ideas? Do you have questions whether they are accurate?	yes after the spider gets to the huge circle it then asks you a question about the topic of thegame trying to figure out the cure	~~Heneed to have~~ so me He need to add sound also
Style What images/color choices work well? What parts stick out?	His game has a background oFthe inside of the humor body whith it shows muscles	

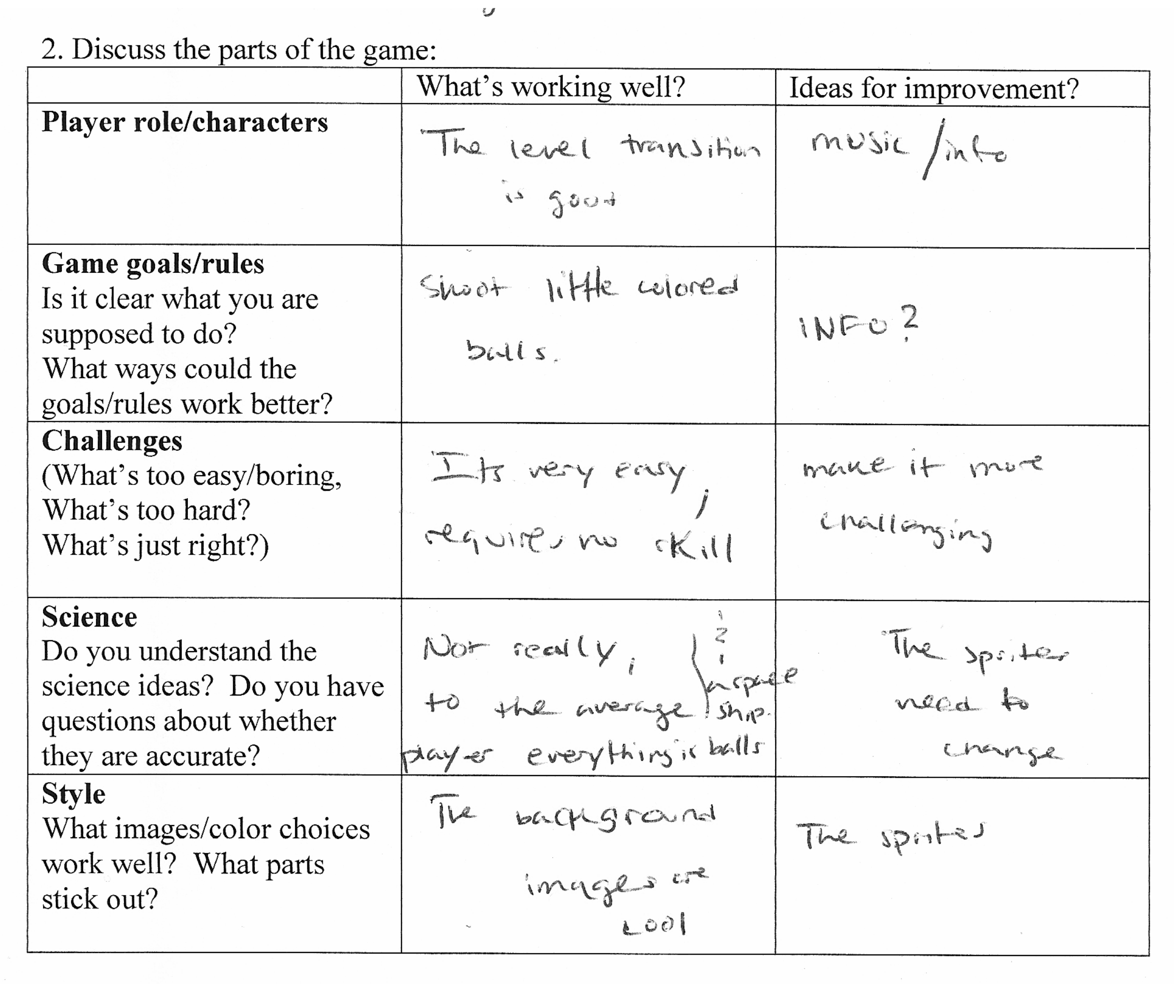
Figure E1. Cameron evaluation.



2. Discuss the parts of the game:

	What's working well?	Ideas for improvement?
Player role/characters PRotect MyeLin SheAth	GLeo ceLLS Being the enemy	None
Game goals/rules Is it clear what you are supposed to do? What ways could the goals/rules work better?	Yes. ~~Better~~	None
Challenges [✓ (What's too easy/boring,] What's too hard? [✓ What's just right?)]	The human destroying the BActeria in the	The ~~None~~ movement of the chARActer
Science Do you understand the science ideas? Do you have questions about whether they are accurate?	yes. MyeLinSheAth	none
Style What images/color choices work well? What parts stick out?	~~The~~ he used Red BLood ceLLS for BACKgROUND	none

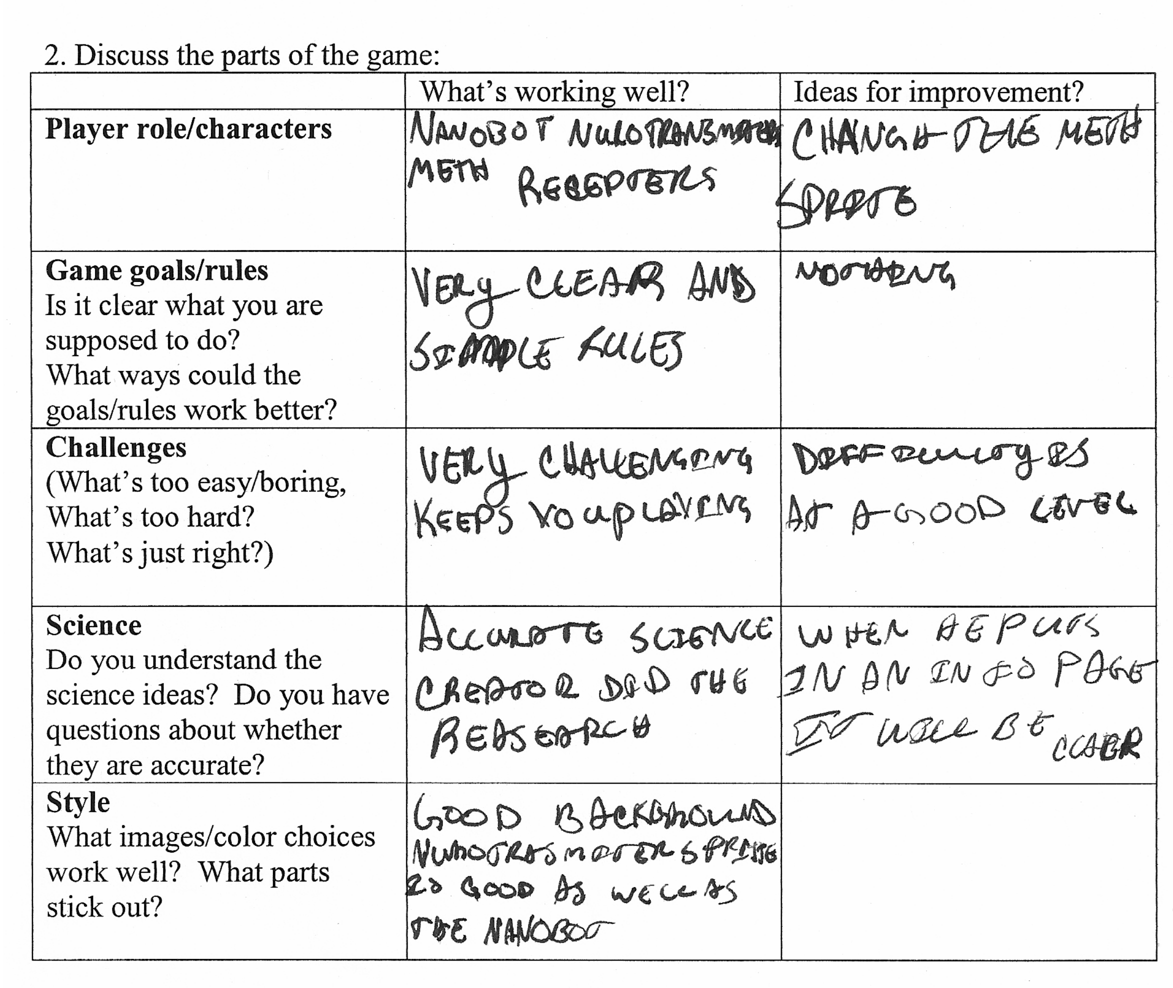
Figure E2. Group-2 evaluation.



2. Discuss the parts of the game:

	What's working well?	Ideas for improvement?
Player role/characters	The level transition is good	music / info
Game goals/rules Is it clear what you are supposed to do? What ways could the goals/rules work better?	Shoot little colored balls.	INFO ?
Challenges (What's too easy/boring, What's too hard? What's just right?)	Its very easy ; requires no skill	make it more challenging
Science Do you understand the science ideas? Do you have questions about whether they are accurate?	Not really ; to the average player everything is balls } ? a space ship.	The spriter need to change
Style What images/color choices work well? What parts stick out?	The background images are cool	The sprites

Figure E3. Wanda evaluation.

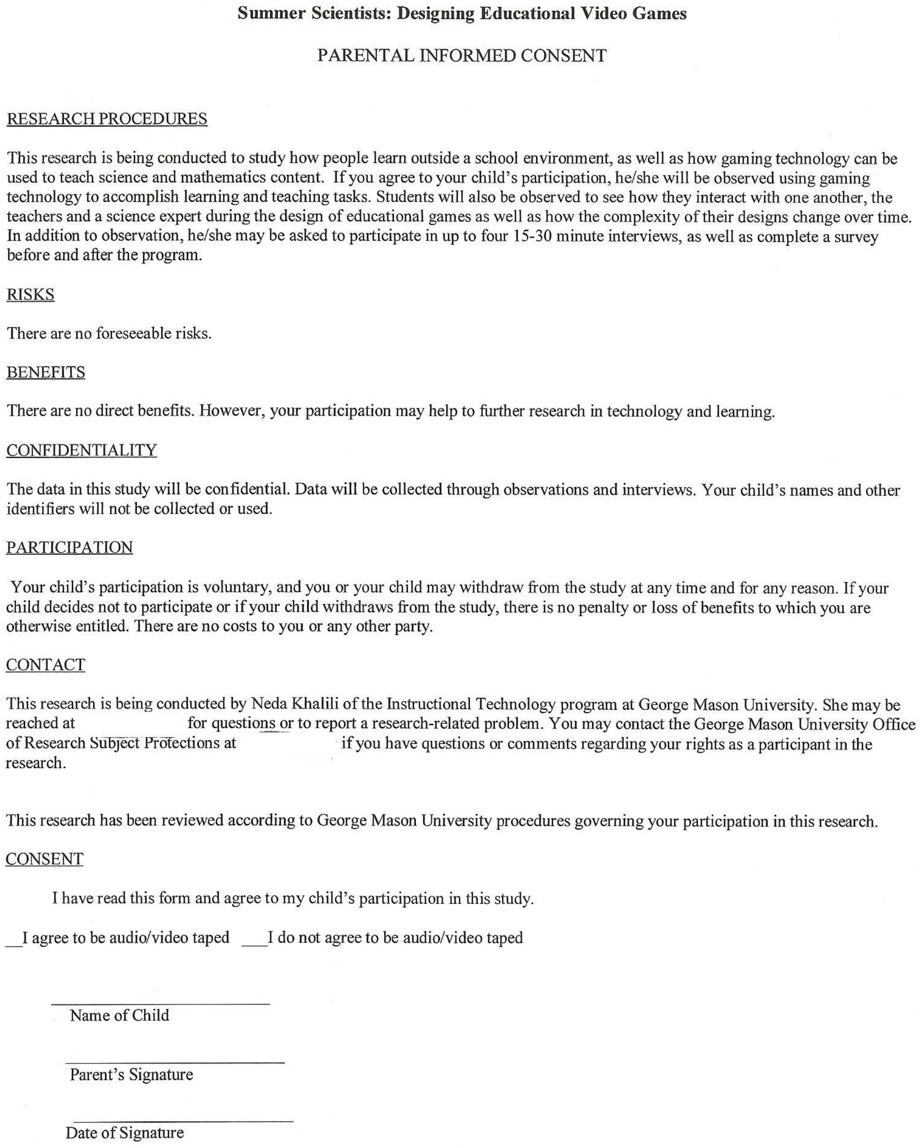


2. Discuss the parts of the game:

	What's working well?	Ideas for improvement?
Player role/characters	NANOBOT NUROTRANSMITTER METH RECEPTERS	CHANGE THE METH SPRITE
Game goals/rules Is it clear what you are supposed to do? What ways could the goals/rules work better?	VERY CLEAR AND SIMPLE RULES	NOTHING
Challenges (What's too easy/boring, What's too hard? What's just right?)	VERY CHALLENGING KEEPS YOU PLAYING	DIFFICULTY IS AT A GOOD LEVEL
Science Do you understand the science ideas? Do you have questions about whether they are accurate?	ACCURATE SCIENCE CREATOR DID THE RESEARCH	WHEN HE PUTS IN AN INFO PAGE IT WILL BE CLEAR
Style What images/color choices work well? What parts stick out?	GOOD BACKGROUND NUROTRANSMITTER SPRITE IS GOOD AS WELL AS THE NANOBOT	

Figure E4. Scott evaluation.

APPENDIX F. IRB APPROVED CONSENT FORMS



Summer Scientists: Designing Educational Video Games

PARENTAL INFORMED CONSENT

RESEARCH PROCEDURES

This research is being conducted to study how people learn outside a school environment, as well as how gaming technology can be used to teach science and mathematics content. If you agree to your child's participation, he/she will be observed using gaming technology to accomplish learning and teaching tasks. Students will also be observed to see how they interact with one another, the teachers and a science expert during the design of educational games as well as how the complexity of their designs change over time. In addition to observation, he/she may be asked to participate in up to four 15-30 minute interviews, as well as complete a survey before and after the program.

RISKS

There are no foreseeable risks.

BENEFITS

There are no direct benefits. However, your participation may help to further research in technology and learning.

CONFIDENTIALITY

The data in this study will be confidential. Data will be collected through observations and interviews. Your child's names and other identifiers will not be collected or used.

PARTICIPATION

Your child's participation is voluntary, and you or your child may withdraw from the study at any time and for any reason. If your child decides not to participate or if your child withdraws from the study, there is no penalty or loss of benefits to which you are otherwise entitled. There are no costs to you or any other party.

CONTACT

This research is being conducted by Neda Khalili of the Instructional Technology program at George Mason University. She may be reached at for questions or to report a research-related problem. You may contact the George Mason University Office of Research Subject Protections at if you have questions or comments regarding your rights as a participant in the research.

This research has been reviewed according to George Mason University procedures governing your participation in this research.

CONSENT

I have read this form and agree to my child's participation in this study.

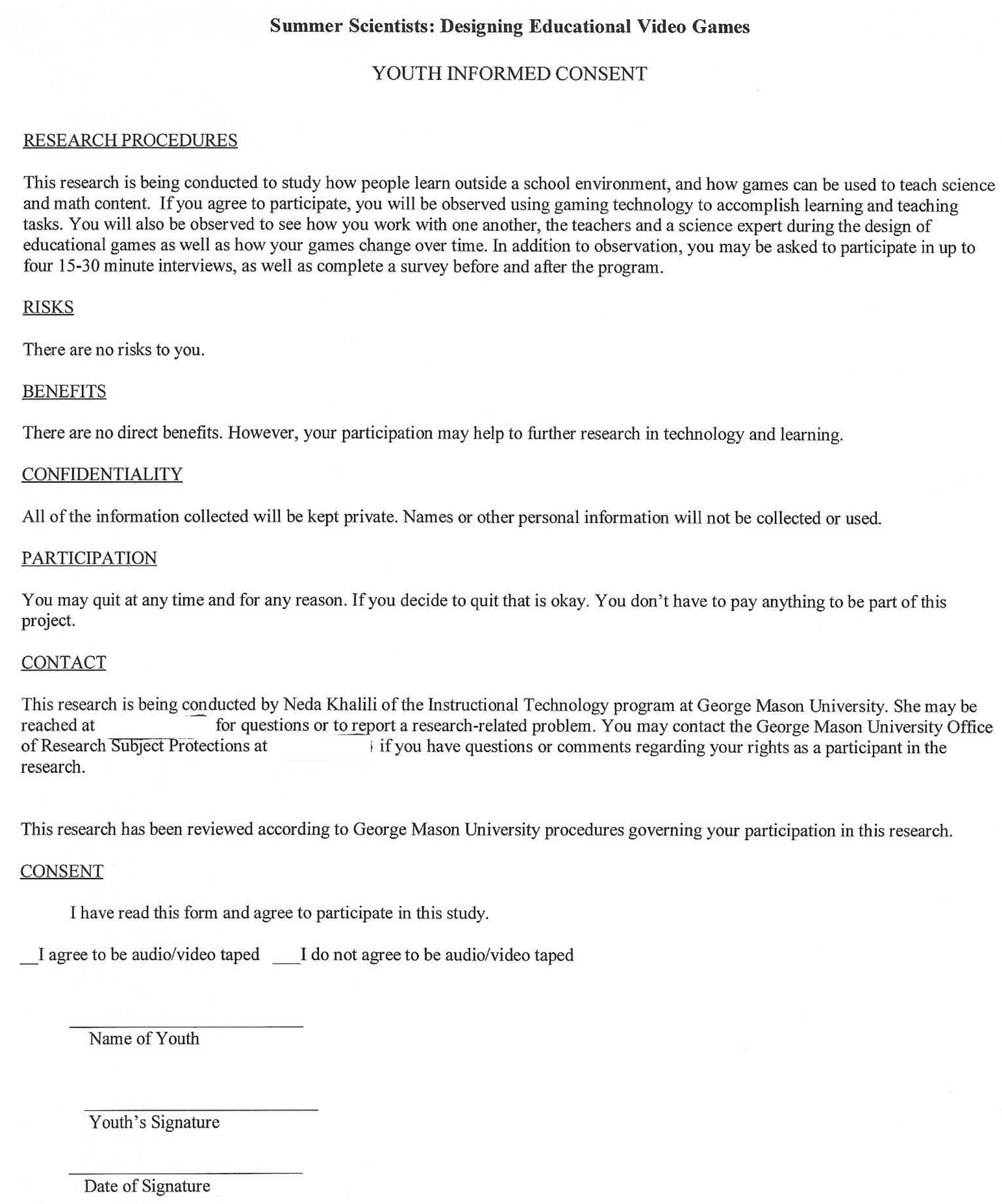
__I agree to be audio/video taped ___I do not agree to be audio/video taped

____
Name of Child

____
Parent's Signature

____
Date of Signature

Figure F1. Parent consent form.



Summer Scientists: Designing Educational Video Games

YOUTH INFORMED CONSENT

RESEARCH PROCEDURES

This research is being conducted to study how people learn outside a school environment, and how games can be used to teach science and math content. If you agree to participate, you will be observed using gaming technology to accomplish learning and teaching tasks. You will also be observed to see how you work with one another, the teachers and a science expert during the design of educational games as well as how your games change over time. In addition to observation, you may be asked to participate in up to four 15-30 minute interviews, as well as complete a survey before and after the program.

RISKS

There are no risks to you.

BENEFITS

There are no direct benefits. However, your participation may help to further research in technology and learning.

CONFIDENTIALITY

All of the information collected will be kept private. Names or other personal information will not be collected or used.

PARTICIPATION

You may quit at any time and for any reason. If you decide to quit that is okay. You don't have to pay anything to be part of this project.

CONTACT

This research is being conducted by Neda Khalili of the Instructional Technology program at George Mason University. She may be reached at for questions or to report a research-related problem. You may contact the George Mason University Office of Research Subject Protections at if you have questions or comments regarding your rights as a participant in the research.

This research has been reviewed according to George Mason University procedures governing your participation in this research.

CONSENT

I have read this form and agree to participate in this study.

__I agree to be audio/video taped ___I do not agree to be audio/video taped

____
Name of Youth

____
Youth's Signature

____
Date of Signature

Figure F2. Youth consent form.

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