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Ready Coder One: Action Research Exploring the Effects of Collaborative Game Design-Based Learning on Gifted Fourth Graders' 21st Century Skills and Science Content Knowledge

Mary Kathleen O'Grady-Jones

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by

Mary Kathleen O'Grady-Jones

Bachelor of Science
University of Illinois Urbana-Champaign, 1986

Master of Science
Northern Illinois University, 1994

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Accepted by:

Michael M. Grant, Major Professor

Fatih Ari, Committee Member

Anna C. Clifford, Committee Member

Hengtao Tang, Committee Member

Cheryl L. Addy, Vice Provost and Dean of the Graduate School

DEDICATION

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ABSTRACT

The purpose of this action research was to describe the impact of digital game building on fourth grade gifted and talented (GT) students' growth in problem-solving, creativity, collaboration, and science content knowledge. Traditionally, gifted education has focused on acceleration of content, disconnected enrichment activities, and thinking skills practiced in isolation of real-world problems. Increasingly, there is a call to involve students in real world experiences through projects that explore real issues using technology in ways that could transform the field. The ability to create rather than consume technology has gained attention linking creativity and collaboration to using coding languages.

Data collection included pre- and postsurvey on creativity and collaboration, pre- and posttest of science concepts, student design and reflection journals, video recordings, focus group interviews and students' games. The participants came from two classes of GT students (*n* = 46). Quantitative data analysis showed significant growth from pre- to postsurvey for the Collaboration Survey. Students showed significant growth from pre- to posttest for the science content knowledge. The Creativity Survey showed no significant difference from pre- to postsurvey although it should be noted that student scores were high at the beginning of the study. Qualitative data analysis revealed five themes including overcoming challenges of group work, developing a culture of

collaboration, creating narrative and connecting science, problem-solving is Scratch's coding environment, and reflecting on learning.

The findings of this study indicate that involving gifted students in game design-based learning in science had a positive impact on student perceptions of their abilities in problem-solving, creativity, and collaboration. Given GT students' reluctance to work in groups, the collaboration scores were particularly relevant. Students took a leading role in learning creating a classroom culture of collaboration. As students encountered coding issues, they sought their own solutions and shared knowledge. Emergence of student expertise led to an environment where students felt comfortable seeking knowledge from each other.

This research has implications for the exploration of ways to support gifted students in their growth in creativity, collaboration, and problem-solving within science. It is also important to note that *all* students need support in 21st century skills.

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CHAPTER 1

INTRODUCTION

National Context

Gifted education has traditionally taken the lead when it comes to research in building critical and creative thinking skills. The growing movement to promote world-class skills (P21, 2009) fits naturally with the goals of gifted education in terms of skill development-creativity, collaboration, and problem-solving. When it comes to integrating technology, the gifted community — while not completely quiet — does not have much to say. Chen, Yun Dai, and Zhou (2013) found that "most of the publications on the topic are still in an advocacy mode, not truly reporting research in the exact sense of the word" (p. 173). Coding has been suggested as a new digital literacy that is critical for GT students (Hagge, 2017; Siegle, 2017). These discussions have been informational or anecdotal. Current research into the use of technology with GT students centers on student motivation (Housand & Housand, 2012) differentiation of instruction (Housand, Housand, & Renzulli, 2017), need for professional development (Besnoy, Dantzler, & Siders, 2012; Robinson, Dailey, Hughes, & Cotabish, 2014), teacher perspectives (Zimlich, 2015), and digital citizenship centered around cyberbullying (MacFarlane & Mina, 2018).

Furthermore, technology integration in gifted education at the elementary school level has even less evidence (Periathiruvadi & Rinn, 2012). The possibilities technology could provide for transforming gifted education in terms of creative and personalized expression outlets are limitless (Chen et al., 2013). Game design-based learning with its unique set of affordances may offer a path to transformation. The benefits of game design-based learning have been explored across grade levels and subject areas. The few game design studies that involved GT students say little about the impact on giftedness in relation to the game design intervention (e.g., Akcaoglu, 2013; Wang, Huang, Hwang, 2016). While many of the studies focus on motivation in general (Akcaoglu, 2013; An, 2016; Hwang, Hung, & Chen, 2014; Tüzün, Yilmaz-Soylu, Karakuş, Inal, & Kizilkaya, 2009; Vos, Van Der Meijden, & Denessen, 2011) and motivation towards science, technology, engineering, and math (STEM) career interests (Jenson & Droumeva, 2015; Kim & Bastani, 2017), others focus on process and artifacts (Baytak & Land, 2011; Ke, 2014; Khalili, 2014; Pedersen, Arslanyilmaz, & Williams, 2009; Salen, 2007).

The process of game planning, designing, and testing, can promote a climate where students turn to each other to solve design problems (Akcaoglu, 2014; Baytak & Land, 2011; Ching & Kafai, 2008). This turning towards peers reflects the type of collaboration and teamwork that are called for by world-class skills and represents a shift in where students go for answers to questions and problems. In the process of game design, students are called upon to analyze and design systems, make decisions about the direction of the game and to troubleshoot programming issues making game design a vehicle for teaching problem-solving skills (Akcaoglu, 2014; Kalelioğlu & Gülbahar, 2014; Li, 2012; Yang & Chang, 2013). These skills align with the Partnership for 21st Century Skills (2009) definition for problem-solving. Increasingly, the ability to create rather than just consume technology has gained attention linking creativity and collaboration to using coding language (Kafai & Burke, 2014; McDooley, Ellison, Welch, Allen, & Bauer, 2016; Sáez López, González, & Cano, 2016).

Local Context

I teach Science, Technology, Engineering, Art, and Math (STEAM) classes for grades K-5 at Cori Elementary School (a pseudonym). In order to protect the identity of participants all state data references have been removed. Cori Elementary School is one of nine elementary schools in a suburban district in the southeast. GT students make up 15.7% of our student population (*N=815*). At each grade level, GT students are enrolled in heterogeneous classrooms. Gifted students are pulled from their class each day to receive instruction in reading, writing, and mathematics from a teacher who is certified in GT. We have a heavy focus on using reading, science, and social studies units that were developed at the College of William and Mary. These units focus on higher questioning, using concept models, and complex problem-solving (CW&M, 2014) that align with 21st century skills (P21, 2009). None of these units involve the integration of technology beyond use as a research tool.

At Cori Elementary, teachers use a variety of technology resources for students including Schoology, Google Classroom, and Discovery Education. Fourth grade students have Chromebooks to access internet resources and complete work. Students are on a seven-day related arts rotation that includes among others, technology, STEAM and Media. The media specialist has created a maker space within the library. Students begin participating in Hour of Code starting in third grade. They are also exposed to both Alice, a block-based programming tool developed at Carnegie Mellon University, and

Scratch, a similar block-based programming tool, developed at Massachusetts Institute of Technology. Both environments have been used in game design-based learning.

In our district there has been a focus on STEAM learning with the intention of building students' world class skills as defined by the Profile of a Graduate. Several teachers have been trained in the use of interactive lessons through Discovery Education. Teachers are in the process of adapting the science kit materials that we have in order to place more emphasis on the processes of experimentation, exploration, and innovation.

The growing interest in STEAM programs and a shift in state standards has caused a refocus on science and engineering skills. State science standards call for student to design and create experiments (creativity) talk to, bounce ideas off, and problem-solving with each other (collaboration and problem solving). These directly match the goals of gifted education, 21st century skills, and state science standards with the affordances of game design-based learning.

Moving towards a classroom that is more collaborative and creative calls for a shift not only in teaching practices but also for student learning behaviors. From my observations over 20+ years of teaching, I have found that students are often more focused on the grade than on the learning. They often do not want to collaborate for fear of someone doing better than they did. They often do not want to try things that are out of their comfort zone. Grant (2016) claims that we do a disservice to our gifted students by continuing to focus on achievement. "Only a fraction of gifted children eventually become revolutionary adult creators" (Winner, 2014 as cited by Grant, 2016, p. 10.) In a time where we need innovators and creators more than ever, we face an educational culture that values achievement over originality (Grant, 2016). This clearly demonstrates a need to shift focus towards achievement that is more inclusive and calls upon the 21st century skills that our students will need to become innovators and problem solvers.

A game design-based learning experience could offer my students the opportunity to practice 21st century skills, gifted goals, and science standards in a game building environment that is focused on building skills and not bound by the constraints of academic achievement. I believe there is room within the science curriculum to situate this unit and offer students the opportunities to explore and experiment.

Statement of Problem

Gifted education, while maintaining high curriculum standards for critical and creative thinking, has limited integration of technology into its recommended instructional strategies of best practices for gifted students. Within many gifted instructional units that are approved by my district, technology is used primarily for research and student presentation using word processing and presentation software. Kafai and Burke (2014) point out that “such activities do not capture the creative and collaborative potential of computing” (p. 116). At the very core of gifted practices are critical and creative thinking skills. The affordances of technology activities such as coding and game design can offer our brightest students’ opportunities to gain not only thinking skills and science skills but also technology skills that could be critical to their futures.

Purpose Statement

The purpose of this action research was to describe the impact of digital game building on fourth grade GT students’ growth in problem-solving, creativity, collaboration, and science content knowledge at Cori Elementary School.

Research Questions

This action research will explore the following four questions about the impact of digital game building.

1. What kinds of problem-solving interactions occur during a game design-based learning science unit for fourth grade gifted and talented students at Cori Elementary School?
2. In what ways will a game design-based learning unit impact fourth grade gifted and talented students' perception of their ability to be creative and innovative in science at Cori Elementary School?
3. In what ways will a game design-based learning unit impact fourth grade gifted and talented students' perception of their collaboration and teamwork skills in science at Cori Elementary School?
4. Will game design-based learning improve knowledge of light and sound concepts for fourth grade gifted and talented students at Cori Elementary School?

Researcher Subjectivities and Positionality for Action Research

I have been an elementary teacher for over 25 years and most of my experience has been teaching gifted students. I remember my first year of teaching. I had five gifted kids and no idea what to do. As a beginning teacher, I was challenged to figure out how best to meet their needs. They were bused to another school one day a week for the gifted program, but the other four days were mine. I found that differentiating through projects was the key. Those five students started me on a journey to learn about gifted education and how to best meet the needs of each individual child.

I am curious about a wide range of topics and open to new learning and understanding. I like to play with new ideas and new technologies. Early on in my use of technologies, I remember becoming stuck and frustrated because something was not working. I stopped and asked myself what would you do if this was a quilting project? I was able to back out of the spot I was stuck in, start taking apart the pieces to find what went wrong. Yes, I was that kid who always took stuff apart to see how it worked. As a kid, I began to recognize that my curiosity sometimes leads me down paths that do not necessarily move me forward, or that move me in directions that are interesting, but not relevant.

I have a Masters in Instructional Design and many years of experience in integrating technology projects into the classroom. I have always been the one that others come to for technology questions. I am also the one who always believes that something big can be accomplished and that together we can do great things. A former principal used to joke that if she wanted something done all she had to do was tell me it was not possible. I loved the challenge and I always found a way.

Recently, I have become frustrated with what I see as ineffective use of technology, and worse, I see the frustration in my students and their parents. I am concerned with the amount of money being spent on technology in schools in hopes of results, but we are just replacing paper with digital. The iPad becomes the textbook and the app replaces the worksheet. Learning management systems have become a dumping ground for content with little interaction for students.

I find myself in the pragmatic paradigm. Pragmatic approaches value the collaboration that I am looking not only to measure in my research but also looking to develop with my students. I was quite taken by Kinash's (2006) description of working collaboratively and even authoring with a student who was involved in the study. I see this as a way to empower students, particularly my gifted students, to become generators of new knowledge. In action research the participant's insights and understandings are valued and add to the body of knowledge being developed. The pragmatic approach looks for individual interpretations of one reality (Creswell, 2014; Hammond, 2013; Margolis, 2003). Working in a school and with students, this understanding will be important. I have struggled with the concept of measuring collaboration and creativity. What do these look like and mean to me? What do they look like and mean to my students? It is clear that our interpretations may be different at the various stages of the research.

A pragmatic approach will allow me to collect data on student thoughts and perceptions. Hammond (2013) describes action research as being a "collaborative and communicative process" (p. 613). I see this as an opportunity to work with my students to build our understanding of what is really happening within the course of this study. I prefer that my positionality be an insider in collaboration with other insiders (Herr & Anderson, 2005), but I need to recognize the power structures that exist and indeed need to exist between a teacher and students. While I see my classroom community as a team or school family, I am ultimately the one in charge of the students. So, in many ways, I am an outsider. I think that with my students and parents, I will need to be honest about the goals and what I hope we accomplish.

This action research will occur in my classroom during the regular school day, I will want to allow students to express their own goals and take ownership of their work or even opt out if they do not feel that this work will be beneficial to them. I will have to be careful that my teacher pleasers, those students who are likely to give an answer they think I want to hear, do not change or hide their thoughts in order to meet my goals. I think honoring their feelings and thoughts throughout the process and treating them as collaborators will be important. I think too that acknowledging that not finding what you expect is part of the process of learning.

I chose my research topic because of both my interest in games and my interest in technology. I am passionate about the value of gameplay in the classroom and the benefits it brings to students. I expect that my study will have a positive impact on students. I know that I will need to be reflective of the impact of my biases on those students who do not resonate with the study I am proposing. So, while I am busy speaking my truth, I need to make sure that my students are empowered to speak their truths.

Definition of Terms

21st century skills-21st century skills encompass a wide range of thinking skills that have become the focus many states as being critical to student success. The Partnership for 21st Century Skills (P21, 2009) while recognizing the importance of contentment knowledge expanded learning to include learning and innovation skills, information, media, and technology skills, and life and career skills. Within this framework collaboration, creativity and problem-solving were highlighted as essential to student success.

Collaboration- Student interactions towards shared or common goals. The Partnership for 21st Century Skills (2009) includes "working effectively and respectfully with diverse teams" as well as "shared responsibility" in their definition of collaboration. Kafai and Burke (2014) point out the effective participation in communities of learning involve searching out, organizing and distributing responsibilities. This collaboration with others was essential to creation of artifacts together. For this study, collaboration was measured by student reflections on "sharing ideas, collaborating on projects, and building on one another's work" (Resnick, 2014, "Introduction," para 3).

Constructionist learning theory- Posits that students build knowledge through construction of artifacts that are both personally meaningful and shared with an audience (Harel & Papert, 1991; Kafai & Resnick, 1996). The artifact represents something to think with and shifts the focus from product to process (Papert, 1993).

Creative self-efficacy- One's beliefs about their ability (Bandura, 1977) to be creative. In science, creative self-efficacy tied to intellectual risk taking in science (Beghetto, 2009) and production of more and varied solutions to problems Brockhus van der Kolk, Koeman, & Badke-Schaub, 2014).

Creativity- Henriksen, Mishra, and Fisher (2016) describe creativity as "a dynamic process emerging through a system of interactions" (p.29). Trilling and Fadel (2009) link creativity to innovation, problem-solving, and invention. Resnick (2014) describes creative learning as the combination of interactions between meaningful projects, peer collaboration, passion, and play. Beghetto and Karwowski (2017) further point out that there must be a balance between originality and usefulness. For this study, creativity was measured by generation of new ideas, design and development of multiple iterations (Resnick, 2014).

Game design-based learning-Resnick (2006) describes the use of computers "like paintbrushes ... opening new opportunities for children to playfully explore, experiment, design, and invent" (p. 192). This will involve students using a game building tool to explore, experiment, design and build their own games.

Gifted and talented- According to the National Association for Gifted Children (2020), gifted individuals show an ability that is significantly above their peers in one or more domains. Domains include intellectual, creative, artistic and academic fields such as mathematics, language, or science, these students are usually score in the top 10 % or higher.

Problem-solving- Partnership for 21st Century Skills (2009) defines problem solving as "analyzing how parts of a whole interact with each other to produce overall outcomes in complex systems." Jonassen, Holland, Moore, and Marra (2003) identify eleven types of problems for learning. Three of these were relevant to game design-based learning decision making problems, design problems, and troubleshooting problems.

Problem-solving within game design- Akcaoglu (2014) identifies three problems associated with game design. They are system analysis and design, decision-making, and troubleshooting. Problem-solving will be defined by "tinkering with materials, testing boundaries, taking risks, iterating again and again" (Resnick, 2014, "Introduction," para 3).

Project-based learning- Project-based learning is student-centered student providing choice in project and process and is centered on a problem that is real world and presents an authentic challenge (Holm, 2011). Components of project-based learning include 1) anchor, 2) task and artifacts, 3) process, 4) resources, 5) scaffolding, 6) collaboration and 7) reflection (Grant, 2002).

CHAPTER 2

LITERATURE REVIEW

Introduction

The purpose of this action research was to describe the impact of digital game building on fourth grade GT students' growth in problem-solving, creativity, collaboration, and science content knowledge at Cori Elementary School.

The review of the literature will focus on four research questions: 1) What kinds of problem-solving interactions occur during a game design-based learning science unit for fourth grade GT students at Cori Elementary School? 2) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their ability to be creative and innovative in science at Cori Elementary School? 3) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their collaboration and teamwork skills in science at Cori Elementary School? 4) Will game design-based learning improve knowledge of light and sound concepts for fourth grade GT students at Cori Elementary School?

Methodology for the literature review

Methods for literature review began by identifying the three key concepts that I am tying together under the umbrella of technology: 1) games, 2) 21st century skills, and 3) gifted education. As I found articles that fit parts of what I was looking for, I expanded search terms for each of the major topics. I made note of keywords and began using those to add to my search collection. I had to look separately for each of the outlined 21st century skills. For several articles, I looked up the author's dissertation to see if it was centered on the same topic. This led to good sources and models to follow.

As my search grew, the term *games* was expanded to include video games, game design, game-based learning, coding, play, artifacts, Scratch, game design-based learning, and connected gaming. An initial search for 21st century skills included, critical thinking, problem solving, creativity, innovation, collaboration, and teamwork. The term *collaboration* was later expanded to include cooperative learning, participatory learning, and participation. It was this later search that lead to the term *connected gaming*. In searching for gifted education, I had two purposes: to discover how technology is currently being used in gifted education and to match the goals of gifted education with 21st century skills. Searches were conducted using a combination of terms from each category.

I used references from articles to become familiar with those in the field studying similar concepts. I would look up articles that were cited as well as use Google Scholar to complete an author search to seek out newer or updated studies.

I had four main sources for searches, *EdSource*, *ERIC*, *ProQuest Dissertations and Theses Global* and the *AECT Member Library*. In searching these databases, I limited my early inquiries to a ten-year period in order to get the most up to date information. I used the AECT Member Library when I was looking for a specific article or author.

My literature review is divided into four sections. The first section will begin by exploring the landscape of technology use in gifted education. The second section will define 21st century skills and their measures. The third section introduces the pedagogies that support technology integration for gifted learners. The final section explores how game design-based learning can be a vehicle for building problem-solving, creativity and innovation, and collaboration and teamwork skills.

Exploring the Landscape of Technology in Gifted Education

In exploring the status of technology use in gifted education, much of the literature focuses on advocacy (Hagge, 2017; Lee, 2011; MacFarlane & Mina, 2018; Siegle, 2004, 2017) rather than research. There is a need in the field of gifted education to study various technology integrations and their impact on gifted students. This research must go beyond how student are consumers of technology to explore how gifted students can become producers and creators with technology (McDooley et al., 2016; Sáez López et al., 2016) This section will include a) an overview of the concept of giftedness, b) current status of research and uses of technology in gifted education, c) potential roles of technology for gifted students, and d) student needs in regards to building digital talents.

Concept of Giftedness

The concept of giftedness typically falls into two categories. Many programs are designed to advance those who are defined as the good lesson learners (Renzulli, 2012; Renzulli & Reis, 2014). This group is represented by their ability to comprehend, store and retrieve information. This learner is usually a good test taker, rule follower, and flat producer (i.e., their products tend to follow directions without deviating). Many current gifted curriculum units are geared toward the good lesson learners. The Center for Gifted Education at the CW&M (2013) produces units of study that promote student achievement through advanced content, reasoning processes, and overarching themes and concepts.

The second category of gifted students is identified as the creative producers. These gifted students are the experimenters, the inventors, the authors, and the artists. They take creative risks (Beghetto & Karwowski, 2017; Kaufman & Beghetto, 2009) and produce artifacts that are significant to those around them (Renzulli, 2012; Renzulli & Reis, 2014)

The Enrichment Triad Model (Renzulli & Reis, 2014) expands the concept of giftedness and reaches to the creative productive potential of students. This further recognizes the students with specific behavioral manifestations of giftedness, for example, specialty in different domains of knowledge, such as leadership, artistic, or creative. The Enrichment Triad Model moves students through three stages 1) general exploratory activities, 2) group training activities, and 3) individual and small group exploration of real problems. General exploratory activities expose students to a wide range of content within a specific domain of knowledge. Group training activities prepare students who show interest and aptitude for a specific subject to engage in deeper research and understanding of a field. In the final stage individuals or small groups are engaged in creating solutions to real-world projects that have an impact outside the classroom. For example, a student may move from learning about an ecosystem to identifying a problem and learning what is already being done, and finally, to creating and sharing their own solution to a local, national, or global issue. This clear alignment with project-based learning will be explored further in a separate section of the literature review.

Current Status of Research and Technology Use

Research on technology use in gifted education is limited (Chen, et al., 2013; Periathiruvadi & Rinn, 2012). Two specific studies highlight the quality and dearth of research with technology use in gifted education.

In 2012, Periathiruvadi and Rinn conducted a review of the literature on gifted education and technology. Over a ten-year period, they found 23 articles that contained empirical research about gifted students using technology. Of those 23 articles, only three addressed issues of technology use in gifted elementary programs. These issues included self-regulation and concentration, strategic thinking through gameplay, and the use of laptops. While each of these efforts helps our understanding of how technology is being used in gifted classrooms, they do not explore how students are using technology in authentic ways to produce representations of their knowledge and understanding.

In an extensive survey of 255 gifted teachers, Besnoy et al. (2012) found that gifted teachers most often used technology to support individual learners as a research tool (79%), for independent learning (73%), to promote student-centered learning (71%), and for individual instruction (65%). Gifted teachers also reported using technology to support student learning groups with cooperative groups (60%) and small group instruction (59%). While gifted teachers used technology as a communication tool (65%), technology was less often used as a productivity tool (54%), or as a problem-solving or decision-making tool (53%). Each of these categories of technology use explores ways in which teachers use technology to support student learning. While the data were collected through a self-reported survey, this points to a trend of technology being used as a vehicle to individualize and differentiate content for gifted learners. For example, Housand and Housand (2012) discuss the benefits of online mentoring opportunities for students in their individual areas of interest. Missing from these examples, though, is how students use technology as creators of new products and information.

Potential Role of Technology in Gifted Education

Among gifted students there is a need to connect and feel a sense of belonging to a community that many high intelligence students do not always feel they receive in their regular classroom setting (Housand & Housand, 2012). Advances in technology offer gifted students the ability to connect with like-minded peers which increases both sense of identity and motivation (Housand & Housand, 2012; Siegle, 2004). For example, Swan, Coulombe-Quach, Huang, Godek, Becker, & Zhou (2015) found that offering virtual labs to rural students increased their skills in collaboration across distances. Students also expressed an appreciation for being grouped with their gifted peers. These feelings of belonging and acceptance foster increased engagement and enthusiasm (Housand & Housand, 2012). Technology can support students by offering the ability to connect across geographic regions with other students who share the same intensity of interest often found in gifted students.

Another advantage to these connections is that technology allows students to work on authentic projects that are of personal interest (Grant, 2011). Advances in technologies allow students to collectively practice a variety of skills that professionals use to create works and solve problems (Siegle, 2004). For example, various mentoring programs connect students with experts in order to collaborate on solving real problems (Housand & Housand, 2012). Technology connects gifted students by lowering barriers to work that is authentic and desired (Siegle, 2004; Zimlich, 2016). Siegle (2004) elegantly states, "Students can be productive draftsmen, composers, and graphic artists by approaching problems and using software in a similar manner as career professionals" (p. 35). This demonstrates the potential transformative power that the affordances of technology can have on the field of gifted education and those students who are identified as gifted.

Technology offers an avenue to expand reach and improve the quality of programs offered to gifted students (Besnoy et al., 2012; Chen et al., 2013; Siegle, 2004). Through technology, the quality of programs is no longer dependent on location. Swan et al. (2015) found that offering virtual learning labs allowed rural students to take advanced courses that their district could not implement in a face to face setting. Given the specialized nature of interests and abilities of some gifted students, the ability to reach out to academic communities beyond the school allows students to access information and mentoring that might not be available at their school.

Moving forward, Chen et al. (2013) point out that there is a need for well-designed research that goes beyond advocacy to explore the role and effectiveness of technology in gifted education. While technology use has many advocates, who recognize the potential benefits of integration for gifted students, the field remains relatively untouched and open to exploration and further research.

Student Needs

Students need guidance as they develop digital literacy, build 21st century skills, and build avenues for creative expression (Besnoy et al., 2012; Chen et al., 2013; Housand & Housand, 2012; Siegle, 2004; Zimlich, 2015). Development of digital literacy skills provides opportunities for students to become efficient and effective problem solvers (Besnoy et al., 2012; Siegle, 2004). An increase in concerns about cyberbullying of gifted students (MacFarlane & Mina, 2018) expands the need to help students build digital citizenship skills that are age appropriate and forward focused. Gifted students are often interested in pursuing knowledge that is beyond that of their peers. Building a safe digital environment for these students to expand their knowledge is essential.

Furthermore, a focus on developing 21st century skills shifts the role of technology from play toy to effective tool for problem-solving (Zimlich, 2015). The Partnership for 21st Century Learning (2009) outlines a range of skills that will be necessary for future success. These include learning and innovation skills, information, media and technology skills, and life and career skills. Under this framework, it is no longer acceptable for students to be merely good test takers and academics. They must become creators, problem solvers, and innovators. In addition, all of these skills need to be practiced in real-world cooperative settings that can be provided through technology interventions.

Defining 21st Century Skills

This section of the literature review explores definitions of 21st century skills. My research focuses specifically on three areas 1) problem solving, 2) creativity and innovation, and 3) collaboration and teamwork. This section will also explore the intersection of gifted education goals and 21st century skills.

Problem-Solving

Problem solving has emerged as a key component for student success not only gifted students but all students. The number of states adopting Partnership for 21st Century recommended skills has increased to 21 states, causing a shift in teaching toward engaging students in more opportunities to engage in critical thinking and problem solve. Problem-solving involves the ability to analyze the interactions of parts in a complex system (P21, 2009), which includes testing boundaries and taking risks (Resnick, 2014). For example, students engage in exploration of possible solutions (Yang, Lin, Hong & Lin, 2016) manipulating and testing materials along the way to a workable solution. The Problem-Solving Inventory (PSI) (Serin, Bulut, Serin & Saygili, 2010) has been used to measure self-perception levels of problem-solving skills. The PSI contains 24 items covering self-confidence in problem-solving (12), self-control (7), and avoidance (5). The inventory was tested on 568 students from grades four through eight and the Cronbach Alpha was found to be at 0.80. Kalelioğlu and Gülbahar (2014) paired the PSI with student interviews and observations to find that student self-perceptions about problem-solving ability were low. The authors further claim that students need more support in learning problem solving skills.

Creativity and Innovation

Interest and exploration of creativity is by no means new to the field of education. Creativity is a dynamic process that balances original and novel ideas with the usefulness of the solution (Beghetto & Karwowski, 2017; Henriksen et al., 2016; Johnson & Johnson, 2014). Creativity is linked to innovation, problem solving, and invention (Trilling & Fadel, 2009). Key creative behaviors include representation invention, component association, outcome improvement, alternative curiosity, and space imagination (Leu & Chiu, 2015).

Creative self-efficacy. Self-efficacy is grounded in a person's belief in their ability to perform a specific task (Bandura, 1977). In a study exploring the differences in creative self-efficacy in students in creative fields and students in technical fields, Brockhus et al. (2014) found that creative abilities and endeavors cross a variety of domains. For example, students in the fields of industrial design and architecture (creative) were compared to students in mathematics and physics (traditionally seen as not creative). Demonstrating that students who believed in their abilities to be creative produced more and varied solutions to problems. Creative self-efficacy was tied to intellectual risk-taking in science (Beghetto, 2009). The scientific process requires the use of both creative thinking and problem solving thus employing divergent and convergent thinking in order to reach creative solutions (Thompson, 2017). The connection between intellectual risk-taking and creative self-efficacy "highlights the importance of science learning environments that encourage and support students in developing their creative self-efficacy beliefs" (Beghetto, 2009, p.219).

Measuring creativity. Creativity is a combination of novel and personally meaningful interpretations that also meet the requirements of a specific task (Beghetto & Kaufman, 2017). Both creativity and problem-solving skills will be necessary to solve myriad complex problems facing our global society (Johnson & Johnson, 2014). When measuring creativity researchers often look to fluency, flexibility, and originality (Guo & Woulfin, 2016; Karademir, 2016; Kashani-Vahid, Afrooz, Shokoohi-Yekta, Kharrazi, & Ghobari, 2017; Kobsiripat, 2015). Fluency refers to the number of solutions to a task.

Flexibility refers to the number of categories a solution falls into. Originality is the uniqueness of a solution. Surveys have been used to measure creative self-efficacy (Beghetto, 2009; Brockhus et al., 2014).

As technology continues to impact global interdependence, developing and encouraging creativity in students becomes essential to their future as creators and innovators.

Collaboration and Teamwork

Collaboration and teamwork involve working effectively and respectfully with diverse teams (P21, 2009) as well as sharing responsibilities, sharing ideas and building on each other's work (Guo & Woulfin, 2016; P21, 2009; Resnick, 2014). Resnick (2017) highlights the natural ways collaboration occurs in the Computer Clubhouse setting. These collaborations include being inspired by other's work but not working together, groups that are attracted by complementary skills, and desire to create a project that is larger than an individual can manage. Johnson and Johnson (2014) posit that knowing how to develop and maintain cooperative systems will be vital to solving the challenges faced in the 21st century. The classroom needs to be a practice ground for these skills. A place where students promote each other's success and in doing so gain positive cognitive outcomes such as articulating solutions to problems, challenging each other's reasoning, and teaching gained knowledge to classmates (Johnson & Johnson, 2014).

Working collaboratively can present challenges for GT students because of their personalities and mindsets (Mofield &Peters, 2018). Some GT traits like heightened emotion (NAGC, 2019), task commitment (Subotnik, Olszewski-Kubilius, & Worrell, 2011), and perfectionism (Mofield & Peters, 2018) can lead to difficulty with group dynamics. Several researchers found that GT students respond positively to group work when they are participating in a task that is challenging, complex, and requires multiple people to complete (Diezmann & Watters, 1997; Lou, Abrami, & d'Appolonia, 2001; Ross & Smyth, 1995; Winstanley, 2010). Salomon and Globerson (1989) suggested that when there is an equitable distribution of workload students responded positively to group work.

Measures of collaboration and teamwork. Co-Measure was developed to assess student collaboration (Herro, Quigley, Andrews, & Delacruz, 2017). This rubric includes peer interactions, positive communication, inquiry rich/multiple paths, authentic approach and task, and transdisciplinary thinking. Within each of these categories the authors list several behavioral benchmarks that can be used to measure collaboration. Reynolds (2016) identified collaborative information seeking (CSI) strategies that included teammate to teammate, student to teacher, and cross team collaborations. Ching and Kafai (2008) used observation to identify collaborative patterns of interaction in a game-design setting. They found that students engaged in periodic monitoring of other's work, responding to direct questions, and immediate intervention such as fixing a problem for another student.

Connection of 21st Century Skills to Gifted Education

In his book *Originals*, Grant (2016) highlights the dangers of continuing to focus solely on achievement for gifted students. Accelerating students farther and faster does not necessarily benefit students. He also points out that our times call for more innovators and creators yet within our school systems we have a culture that values achievement over originality (Grant 2016). The Three-Ring Conception of Giftedness explores the intersection of ability, task commitment and creativity (Callahan, Moon, Oh, Azano, & Hailey, 2015; Renzulli & Reis, 2014). Within this model a student's creative giftedness emerges based on exposure to specific domains or areas of interest. This type of giftedness is more closely tied to specific problems where action including creative production, collaborative exploration of a topic and problem-solving are valued more than traditional test results. The Enrichment Triad Model was developed to offer opportunities for students to first explore topics of interest, then gains skill sets and finally to take action thus promoting thinking skills and creativity (Callahan et al., 2015; Renzulli & Reis, 2014). These represent a shift in thinking about gifted students and the types of learning experiences that they will need for a successful future.

Pedagogies to Support Game Design-Based Learning

There are three main pedagogies that support technology in gifted education. I begin by examining constructionist learning theory, followed by project-based learning, and then how game design-based learning is situated in these pedagogical foundations.

Constructionist Learning Theory

Constructionist learning theory (Harel & Papert, 1991; Kafai & Resnick, 1996) focuses on building knowledge through construction of artifacts that are both personally meaningful and shared either locally or with a broader audience. Constructionist based learning environments offer students the opportunity to engage in meaningful projects that connect them to the world beyond the classroom. Papert (1993) referred to the artifacts as objects to think with shifting the focus from product to process. Design tools such as Scratch provide students with that object. Students can explore concepts, reformulate ideas and implement their own designs (Baytak & Land, 2011). Artifacts should reflect student learning (Grant & Branch, 2005; Marx, Blumenfield, Krajcik, & Soloway, 1997).

Artifacts may take on many forms, but they must be shareable with the broader community (Marx et al., 1997) and represent an authentic effort to solve real-world problems (Holm, 2011).

Another element of constructionist learning is the social aspect of learning. "Learning flourishes as a social activity, with people sharing ideas, collaborating on projects, and building on one another's work" (Resnick, 2014, p. 1). Constructionist learning promotes playful experimentation. Testing and repeated trials are a valuable part of the learning process where students are encouraged to test and improve on their designs (Baytak, 2009; Resnick, 2014). An underlying assumption of constructionism is that the design activities have social relevance for all students in the setting (Rieber, Davis, Matzko, & Grant, 2001). For example, Baytak and Land (2011) had students design games based on environmental issues to be shared with younger students at their school. Students were given opportunities to make personal choices and they created their artifacts with a broader audience in mind. This allows students to make personal and meaningful connections with new knowledge (Papert, 1993). Within the context of game design-based learning, students are building and sharing games that have personal value as well as social value.

Project-based Learning

Project-based learning is student-centered in that it involves student choice in both project and product around a problem that is real world and presents an authentic challenge (Holm, 2011). Learning occurs when students are working on projects that are personally meaningful (Grant & Branch, 2005; Resnick, 2014). The process of generating new ideas, designing prototypes, and repeated refining engages student problem solving and thinking skills (Holm, 2011). Components of project-based learning include 1) anchor, 2) task and artifacts, 3) process, 4) resources, 5) scaffolding, 6) collaboration and 7) reflection (Grant, 2002). Each of these is described in further detail below.

Anchor. The anchor or driving question (Holm, 2011; Marx et al., 1997) provides the backdrop for the learning and development of projects. This anchor needs to meet three criteria a) worthwhile and meeting with the existing curriculum, b) encompass real-world problems that are meaningful to students, and c) present a match with student knowledge and skill sets (Marx et al., 1997). Each of these acts in order to launch students into a successful project-based learning experience. For example, Grant (2011) explored a project-based learning unit that was anchored in the concepts of civil rights. This gave students a real-world problem that was meaningful and at the same time achievable for learners.

Task and Artifact. The task will lead students through discovery to the creation of their own personally meaningful artifact. Artifacts allow students to concretize knowledge by creating objects that embody ideas (Baytak, 2009; Baytak & Land, 2011; Grant, & Branch, 2005; Kafai, & Resnick, 1996; Kafai & Burke, 2014). Technology projects can take many forms including but not limited to presentations, websites, interactive games, or recorded performances.

Process/Resources. Outlining the steps to begin a project-based learning experience helps students to focus their efforts. In project-based learning teachers serve as resource, facilitator, and guide. Teachers model thinking and structuring of the problem to facilitate student independence (Marx et al., 1997). For example, students can engage in WebQuests that guide them through relevant resources (Grant, 2011). These resources help students access information that is both relevant to the project and age appropriate.

Scaffolding. Scaffolding can take on many forms from questioning and brainstorming to electronic forms or project management resources. For example, student can be provided with templates for information gathering (Grant, 2011). Teacher scaffolding provides the structure and support that students need to be successful in project-based learning.

Collaboration. Within project-based learning student collaboration becomes an essential part of student growth. Students share ideas, extend their thinking, and become experts to each other (Marx et al., 1997). Elements such as structured peer reviews and reflections allow students to give and receive critique of work throughout the process (Grant, 2011). Collaborations reaching beyond the walls of the school extending toward the community add value to the learning experience (Marx, et al., 1997).

Reflection. Reflecting on learning and planning for future projects is a key element to successful learning. Reflection involves relating new information to existing knowledge and understanding how learning and problem-solving strategies can be applied to future situations (Hmelo-Silver, 2015) Helping students reflect through the use of short responses at the end of class or design logs builds closure for the learning experience (Grant, 2011).

Game Design-Based Learning

Much interest in game design grew out of the demand for students to understand computer science and computational thinking. The New Media Consortium Horizon Report (2017) listed coding as a form of literacy that will drive K-12 technology adoption over the next two years (Adams Becker, Freeman, Giesinger Hall, Cummins, & Yuhnke, 2016). Opportunities for students to learn coding skills are growing through organizations such as Hour of Code, Girls Who Code, and Google's CS First.

Many platforms for coding and game design have emerged. ALICE and Scratch are two examples. ALICE is a visual programming language developed at Carnegie Mellon University. ALICE is a block-based programming environment that allows students to build interactive narratives and games. Scratch was developed at Massachusetts Institute of Technology (MIT). Scratch is especially appealing to younger children because it has a ‘‘low- floor (easy for the students to pick up) and high-ceiling (allow students to create more sophisticated programs)” (Lye & Koh, 2014, p. 54). Researchers (Baytak & Land, 2011; Lye & Koh, 2014) have found that elementary students are able to access advanced levels of programming concepts using Scratch.

Vos, Van Der Meijden, and Denessen (2011) compared playing games to learn code and teaching code in the context of game design and found significant differences between groups in both motivation and deep strategy. They further reported that game construction enhanced student motivation and students enjoyed game design more than the game playing experiences.

Game design-based learning has been studied by numerous researchers in both formal classroom settings (Baytak & Land, 2010, 2011) and informal camp (Akcaoglu,

2014) and club settings (Burke, O'Byrne, & Kafai, 2016; Kafai & Burke, 2014). While each setting is unique, they all share some common characteristics that include 1) context, 2) game design and building activities, 3) teacher/ mentors 4) collaboration, and 5) reflection.

Context. Whether the context is curriculum based in science, social studies, or developed out of student interest, in game design students are involved in developing rich complex worlds that have narratives, rules, conflicts (Yang & Chang, 2013). Creation of these worlds engages students in activities that cross over several knowledge domains. Herro et al. (2017) describe this as transdisciplinary approaches within the context of STEAM education.

Game design and building activities. Many game design and building activities offer students insight into the structure used in games. These activities include deconstructing games, modifying existing games, and story development for games. Deconstructing existing games allows students to explore and understand both programming and game mechanics (Reynolds, 2016). Game modding (modifications to existing games) has become popular and more accessible to players (Kafai & Burke, 2016). Students are already engaged in making the games that they play more personalized. This trend has made game deconstruction and reconstruction a natural part of the gaming world. Akcaoglu (2016) uses the acronym GRASPS to help student identify basic game elements including Goals, Rules, Assets, Spaces, Play mechanics and Scoring. Identifying elements of games and creating flow charts of games allows students to see the complex systems involved in game design (Akcaoglu, 2016). When students are introduced to specific problem-solving challenges there is an opportunity to teach problem solving skills along with game design (Akcaoglu, 2016). These included opportunities for students to engage in decision-making, systems analysis, and troubleshooting of programs.

Collaboration. Collaboration plays a large role in game design, students become experts in programming and are eager to share (Hwang et al., 2014; Ke & Im, 2014). Ching and Kafai (2008) found that as students worked whether in clusters or individually, they engaged in monitoring of others progress, pauses to respond to questions, and immediate interventions. Student interactions around problem-solving include suggesting improvements, dialoguing about challenges and directly responding to requests for help by fixing problems in another person's program (Ching & Kafai).

Reflection. Repeated testing, improvements and redesigning are a part of the reflective process in game design learning (Baytak, 2009). This allows students to share their growth experiences as they discover new understandings. Baytak (2009) in a study where fifth grade students designed games for second graders found that having feedback from the intended audience showed students the gaps in their games. These students responded reflectively and planned to make their work better.

Game Design as Project-based Learning

Game design-based learning fits under both constructionism and project-based learning. Table 2.1 summarizes the parallels between the elements of project-based learning and the elements of game design-based learning. The following section explains the specific connections between project-based learning and game design-based learning including 1) anchor, 2) task and artifacts, 3) process and resources, 4) scaffolding, 5) collaboration, and 6) reflection.

Table 2.1. *Comparison of Project-based Learning to Game Design-Based Learning*

Components of Project-based Learning (Grant, 2002)	**Components of Game Design-Based Learning**
Anchor	Context for game design
Task and Artifacts	Game Design and Building Activities
Process Resources	Deconstructing games Design activities Troubleshooting Problem-solving challenges
Scaffolding	Teachers/Mentor roles in Game Design-Based Learning • Catalyst • Consultant • Connector • Collaborator (Resnick, 2017)
Collaboration	Clustered work-student interactions • Information seeking strategies (Reynolds, 2016) • Suggestions for improvement • Dialogue about challenges • Directed response • Fixing other's programs (Ching & Kafai, 2008)
Reflection	Iterations of design Sharing and critiquing

Anchor. The anchor for game design-based learning can come from student interest or it can be driven by the needs of curriculum. In several game design studies the anchor came from standards or needs of the school setting such as social issues (Ruggiero, 2017), biology (Yang & Chang, 2013), environmental issues (Baytak, 2009, Baytak & Land, 201), Newton's Laws of Motion (Li, 2010) and social studies topics (An, 2016; Vos et al., 2011) among others. The context of the coursework serves as the anchor for further investigations and the underlying theme of the games that are built.

Task and Artifacts. Within game design-based learning, students are called upon to construct worlds that include characters, rules, interactions, and conflicts (Kafai & Burke, 2016, Yang & Chang, 2013). The task in game design-based learning is the design and development of a playable game and all its elements. The development process allows student to further explore a given topic as they incorporate details and concepts into their work.

Process and Resources. The process and resources for game design-based learning include activities such as deconstructing games (Reynolds, 2016), design challenges, troubleshooting code (An, 2016; Akcaoglu, 2014) and problem-solving challenges (Akcaoglu, 2014). The resources that are made available would fit into the category of "just in time" support (Renzulli, 2012, p. 154)- that which students need in a given time to move forward in their learning. This shifts the role of the teacher to that of a mentor providing scaffolding more often than direct instruction.

Scaffolding. The roles of the mentor include catalyst, consultant, connector, and collaborator (Resnick, 2017). The catalyst asks questions to encourage exploration and spark ideas. The consultant is there to advise, support, and encourage. The connector helps students find others with expertise that they may need. This includes connecting students to each other for the purpose of collaboration.

Collaboration. Collaboration among students is an important part of both game design-based learning and project-based learning. Collaborations are not limited to students-to-student interactions, teachers and mentors become involved in their own projects that they invite students to join (Resnick, 2017). Reynolds (2016) identified collaborative information seeking strategies that included, collaboration between teammates using their own expertise, teammates accessing digital resources, cross team collaborations using their own expertise, classmates accessing digital resources, teacher collaboration using his/her own expertise, and teacher working with students to access digital resources. Ching and Kafai (2008) through observation of students engaged in game design noted that students tended to work either independently or in clusters. Independent students collaborated through periodic monitoring and responding to questions. Their responses included offering suggestions, engaging in dialogue, and giving directions (Ching & Kafai). Student who worked in collaborative groups tended to respond to questions and engage in immediate intervention. Their response included engaging in dialogue, giving directions, and stepping in to fix issues. In the context of game design-based learning students collaborate in various ways that are authentic to real-world problem-solving situations.

Reflection. Through various iterations of game design, testing, and troubleshooting, students are called upon to reflect on what is working and what needs to be improved (Baytak, 2009; Baytak & Land, 2011; Prater, 2016). For example, Baytak and Land (2011) had students test drive their games with their younger target audience. This reflection takes place repeatedly as students build, evaluate, change, and refine their designs (Øygardslia, 2018; Pareto, Haake, Lindström, Sjödén, & Gulz, 2012; Salen, 2007). "Thus, the students continually re-conceptualized their ideas throughout the design process" (Baytak, 2009, p.113).

Game Design-Based Learning to Build 21st Century Skills

In this final section of the literature review, 21st century skills will be reexamined in the context of game design studies that have been carried out. This demonstrates how problem-solving, creativity and innovation, and collaboration and teamwork each play a critical role in successful game design learning environments.

Problem-Solving

When students engage in game design learning, they face several challenges that require problem solving. Games are complex systems and game design challenges present ill-structured problems (Jonassen, 1997) where students are called upon to analyze the systems in order to create their finished product (Akcaoglu, 2014; Ruggiero & Green, 2017). Students gain practice in system analysis and design, decision-making, and troubleshooting (Akcaoglu, 2014). For example, students need to analyze interactions within the structure of a game to ensure that a game has a balance of challenge and success (Kim & Bastini, 2017; Prater, 2016).

Several researchers (Akcaoglu, 2016; Cicchino, 2013; Su, Yang, Hwang, Huang, & Tern, 2014) found that teaching problem-solving skills in conjunction with programming and game design leads to higher levels of critical thinking. Akcaoglu (2014) built problem solving activities into the game design cycle where specific skills were taught to scaffold students in the process. Akcaoglu presented complex problem scenarios, guided problem-solving, and then students engaged in creating simulations within the game building program. Troubleshooting opportunities were also presented to students in the form of games that did not work or that were missing code. Students worked through the code to discover and fix what was wrong. Teaching specific skills through the game design process allowed students to grow in their abilities to problem solve in the areas of system analysis and design, decision-making, and troubleshooting (Akcaoglu, 2014). Through this process the author found that students showed significant gains in problem-solving skills.

Within game design-based learning, students are using decision-making skills to plan and create complex narratives, that include characters and backgrounds, game rules and tasks, elements of challenge, quests and role-playing in addition to the demands of programming and graphic design (Akcaoglu, 2014; Ruggiero & Green, 2017; Yang & Chang, 2013). Furthermore, the act of testing games and giving peer feedback requires students to utilize critical analysis skills (An, 2016). The varied types of problems students encounter in game design learning make it a rich playground for students to explore and practice problem-solving skills.

Creativity and Innovation

The act of building a complex game in and of itself represents an act of creation. Yet while there are many claims to game design-based learning growing creativity, Qian and Clark (2016) found that few studies of game-based learning actually measured growth in creativity. Yang and Chang (2013) point to the challenges inherent in game design such as, narratives, characters, conflicts, and other design elements, as advantages for development of creative thinking.

With the rise in access to coding platforms, such as Scratch where students can access complex coding and engage in modifications to others work, opportunities for creative expression and innovation are abundant. Through exposure to creative thinking experiences in game design learning students become active learners, creators and evaluators (An, 2016; Navarrete, 2013). Creativity is enhanced through the game design experience and linked to social context (Johnson & Johnson, 2014; Li, 2010). The ability to create rather than just consume technology is becoming an essential skill (Sáez López et al., 2016). Creativity and innovation are a part of the 21st century skills framework and need to be explored and encouraged for student growth. Game design-based learning offers many opportunities for students to develop creativity skills through building game worlds that have rich and complex characters, narratives, rules, and challenges.

Collaboration and Teamwork

The game design process offers opportunities for students to collaboratively practice problem-solving skills (Akcaoglu, 2014; An, 2016; Reynolds, 2016). Within the context of game design teams, students take on various roles to negotiate team norms, decision-making protocols, and project management (Ke & Im, 2014; Reynolds, 2016). An (2016) found that students naturally collaborate sharing ideas and strategies thus becoming active cooperative problem solvers even when they were not assigned to the same teams. Reynolds (2016) found that collaborative information seeking norms evolved as students established project management and group decision making protocols. Through this process students relied on each other's expertise to solve design or programming problems (Reynolds, 2016). Game based learning offers rich opportunities for teachers to guide students in the development and practice of collaborative problem-solving skills.

Within game design-based learning, problem-solving, creativity and innovation, and collaboration and teamwork all play important roles in the success of a project and the growth of student skills. Problems are often solved collaboratively (Ching & Kafai,

2008) and creative projects are grown from collaborations or remixing of previous work and borrowed ideas (Resnick, 2017). This makes game design-based learning a rich environment for students to practice 21st century skills.

Chapter Summary

Gifted education is poised for growth in terms of its potential for research in technology innovations. Advocates are calling for increased innovations to meet the needs of gifted learners (Besnoy et al., 2012; Chen et al., 2013; Siegle, 2017). Along with demands for increasing student capabilities in 21st century skills, gifted curriculum is shifting to promote the practice of problem-solving, creativity and innovation, and collaboration and teamwork (Renzulli, 2012; Renzulli & Reis, 2014) in ways that engage students in real world projects that have audiences beyond the classroom and school walls.

Constructionist pedagogies and project-based learning offer guidance for structuring learning experiences that have been proven successful in developing these skills. Game design-based learning has been explored with many populations. Game design, testing and troubleshooting provide opportunities for students to practice and problem-solving (Akcaoglu, 2014; Ruggiero & Green, 2017; Yang & Chang, 2013). Creativity inherent in the game design process will allow students to explore coding and create artifacts that are meaningful to both the individual and the group (An, 2016; Li, 2010; Navarrete, 2013). Students involved in game design activities benefit from the social aspect of peer assessment (Hwang et al., 2014; Ke & Im, 2014), peer-to-peer teaching (Akcaoglu, 2016; Reynolds, 2016), and team design activities (Ke & Im, 2014).

The overlaps between game design-based learning, 21st century skills, and the Three Ring Conception of Giftedness (Renzulli & Reis, 2014) present a unique opportunity to explore the effects of game design for gifted students. Gifted students bring creativity, commitment, and intellectual strengths to the task. Anchoring game design-based learning within the constructs of project-based learning gives a proven structure to student work in exploring problem-solving, creativity, and collaboration skills. As students move through the process of game design-based learning, from task and artifacts to collaborations and reflections, they will face many opportunities to problem-solve, work as a team and to exercise creativity

CHAPTER 3

METHOD

The purpose of this action research was to describe the impact of digital game building on fourth grade GT students' growth in problem-solving, creativity, collaboration, and science content knowledge at Cori Elementary School. My research questions included: 1) What kinds of problem-solving interactions occur during a game design-based learning science unit for fourth grade GT students at Cori Elementary School? 2) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their ability to be creative and innovative in science at Cori Elementary School? 3) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their collaboration and teamwork skills in science at Cori Elementary School? 4) Will game design-based learning improve knowledge of light and sound concepts for fourth grade GT students at Cori Elementary School?

Research Design

As my work was grounded in constructionist learning, I found myself open to the unknown possible, that my students and I collectively constructed by engaging in this research. In the Introduction to *Constructionism*, Harel and Papert (1991) explored the ideas of constructing our own understandings of constructionism. I borrowed their use of stories to demonstrate the evolution of constructionism and illustrate the evolution of my ideas. I have always been a tinkerer and a creator. Summers in my neighborhood were spent building things from cardboard, wires found in the alley, and whatever other materials came our way. I remember taking apart anything mechanical just to see how it worked. As a teacher, I have always embraced the idea of "let's try it and see what happens." Sometimes this led to great success and other times to utter failure. As a graduate student in the 1990s, I had the fortune to meet with David Jonassen who was visiting my university. In a conversation about constructionism, I told him of some of my great failures at attempting a constructionist learning environment. I was frustrated because I wanted it to work. He told me that student constructions would only be as sound as the foundations they are built on (D. Jonassen, personal communication, 1994). I have reflected on that idea over the years and have worked with students to build strong foundations for their constructions. Like Kinash and Hoffman (2008), I saw students not as participants that I observed but as partners in discovery. While I had carefully built my foundation for this research, I had to admit a little bit of me was excited about constructing and discovering this learning with my students.

This research was done with two of my STEAM classes and I was a full participant in the actions that I studied (Fraenkel, Wallen, & Hyun, 2015). It was this connection to my students and my role as both teacher and researcher that action research revealed itself to be the appropriate format for this inquiry. Action research by its very nature involves practitioners or other stakeholders invested in the teaching and learning in a specific situation to systematically study and reflect on their practice (Herr & Anderson, 2005; Mertler, 2017).

Three key aspects to action research made this an appropriate manner of inquiry: 1) it is designed to bring about change from within (Mertler, 2017); 2) it is collaborative in nature (Hammond, 2013; Herr & Anderson, 2005; Kinash, 2006); and 3) it is a reflective process (Herr & Anderson, 2005; Mertler, 2017). The work within my classroom had the purpose of exploration of game design-based learning to bring about change. Ultimately, I wanted to have an impact on the learning that was done not only in my classroom but also at my school. I believe that my students' views and understandings of what was going on to be of equal importance to my own views and understandings. Developing the collaborative working relationship was essential to obtaining the qualitative data that I sought. Reflection on classroom events by all stakeholders tied all the elements of action research together and pointed to the next steps in my practice as a teacher and a researcher and hopefully some next steps for my students as well.

Creswell (2014) recommends that in deciding an approach to research, the researcher considers among other things, personal experience, research questions and audience. I admit to feeling more comfortable with qualitative methods, but I felt that quantitative data would strengthen both my work and my understanding.

This descriptive research most closely followed the triangulation mixed-methods design (Mertler, 2017; Fraenkel et al., 2015). I collected both quantitative and qualitative data throughout the study and the various data points converged to present one holistic picture of the game design-based unit (Fraenkel et al., 2015). Triangulation mixed-methods design places a focus on interpretation of both qualitative and quantitative results (Creswell, 2014; Mertler, 2017), which fits my goal of describing and understanding the impact of game design-based learning. This focus on interpretation also fits well with the reflective nature of action research. These interpretations also helped with my goal, moving gifted programs at my school towards a new way of building skills in problem-solving, creativity, and collaboration.

Setting

This action research took place in my STEAM classroom at Cori Elementary School. Cori Elementary is designated as a STEAM school and all teachers are working to emphasize the engineering design cycle: 1) ask, 2) imagine, 3) plan, 4) create, and 5) improve. Students attended a 45-minute STEAM class as part of the seven-day related arts rotation. During a nine-week period, students attended class six to seven times. The school has invested in a variety of materials to support STEAM learning. These included units from Project Lead the Way, Engineering is Elementary, and LEGO Education resources. Each of these resources were designed to involve students in problem-solving and design challenges. Students participated in Hour of Code each year and by third grade all students had access to a Scratch account to assist in the development of coding skills. In addition, both the technology lab and the STEAM classroom made use of Google's CS First resources, designed to teach students computer programming skills.

Each fourth-grade classroom had a set of 20 Chromebooks. In addition to STEAM classes, students had a technology lab class where they have one-to-one access to computers. Both technology and STEAM shared the responsibility of teaching the state computer science and digital literacy standards. My STEAM classroom had two student desktops, six student laptops and fourteen iPads.

There were seven fourth grade classes in our building. All fourth-grade students switched classes for math and language arts. It was during this time that gifted students were clustered together to receive gifted services. Students returned to their homeroom teacher for instruction in science and social studies. Fourth grade science standards were divided into four units, including Weather and Climate, Stars and the Solar System, Forms of Energy: Light and Sound, and Characteristics and Growth of Organisms. Students and teachers had access to the Science Techbook through Discovery Education (Discovery Education, 2017). The Techbook presented information through articles, videos and some interactive games and simulations. We also used the Foss Science kits which include informational books for students, science equipment, and prescribed experiments.

Participants

The participants in this study came from the two GT classes in the fourth grade (*n*=45). Informed consent (see Appendix A) was obtained from both parents and students to participate. These students came to STEAM with their GT cluster classes. In this group there were 16 females and 29 males. Of these students, 78% were Caucasian, 22% were minority including Asian, African Americans, Hispanic, and biracial. Students were selected for the gifted program based on test scores and were considered gifted in one or more of three domains: verbal, quantitative, or nonverbal. Some students' scores lead them to be considered both quantitatively (as measured by the mathematics portion of the Cognitive Abilities Test (CogAT) or Measures of Academic Progress (MAP) and verbally gifted (as measured by the reading portion of CogAT or MAP). Nonverbally gifted students were those who demonstrated strengths in visual and spatial problem-solving (Lohman, 2005). Table 3.1 displays the assessments used to assign domain of giftedness and the number of female and male students in each category. In this group of students, 28 were coded as both verbally and quantitatively gifted, six students were quantitatively gifted, seven were verbally gifted, and four students were identified as nonverbally gifted.

Table 3.1 *Participants Areas of Identification and Assessments*

Areas of Identification and Assessments Used	Female	Male	Total
Overall CogAT Score +96%	5	11	16
Verbal and Quantitative CogAT MAP, STAR, or State Testing	5	7	12
Quantitative Only CogAT, MAP, STAR	0	6	6
Verbal Only CogAT, MAP, STAR	5	2	7
Nonverbal CoGAT, STAR	2	2	4

Note: An overall score of 96% or above on CogAT places a student in GT without further assessments. (State Best Practices Manual)

Innovation

The game design-based learning unit for GT students took place over the course of the spring 2019 semester. Students met in the STEAM lab thirteen times during the semester to work on game design activities and game production. Each class period lasted 45 minutes. The project was anchored in both project-based learning and game design-based learning and follows the elements of both (see Table 3.2).

Table 3.2. *Comparison of Project-Based Learning to Game Design-Based Learning*

Components of Project- Based Learning (Grant, 2002)	**Components of Game Design-Based Learning**	**Game Design-Based Learning for Gifted Students**
Anchor	Context for game design	Science concepts of light and sound
Task and Artifacts	Game Design and Building Activities	Design and build a game to teach second grade students about light and sound
Process Resources	• Deconstructing games • Design activities • Troubleshooting • Problem-solving challenges	• Flow charts and GRASPS (Akcaoglu, 2014) • Light and sound stations
Scaffolding	Teachers/Mentor roles in Game Design-Based Learning • Catalyst • Consultant • Connector • Collaborator (Resnick, 2017)	"I have a question." board
Collaboration	Clustered work-student interactions • Information seeking strategies (Reynolds, 2016) • Suggestions for improvement • Dialogue about challenges • Directed response • Fixing other's programs (Ching & Kafai, 2008)	The "I have a question." board will be used to help students connect with each other to collaborate on problem-solving
Reflection	Iterations of design Sharing and critiquing	Students will receive feedback from peers and their target audience. They will be involved in redesigning and finalizing their games. Design journals will be used as a reflection tool and a place to respond to reflection questions.

The academic anchor for this learning was an exploration of light and sound energy as defined by the state science standards for fourth grade.

Standard 4.P.4: The student will demonstrate an understanding of the properties of light and sound as forms of energy.

4.P.4A. Conceptual Understanding: Light, as a form of energy, has specific properties including color and brightness. Light travels in a straight line until it strikes an object. The way light reacts when it strikes an object depends on the object's properties.

- 4.P.4A.1: Construct scientific arguments to support the claim that white light is made up of different colors.
- 4.P.4A.2: Analyze and interpret data from observations and measurements to describe how the apparent brightness of light can vary as a result of the distance and intensity of the light source.
- 4.P.4A.3: Obtain and communicate information to explain how the visibility of an object is related to light.
- 4.P.4A.4: Develop and use models to describe how light travels and interacts when it strikes an object (including reflection, refraction, and absorption) using evidence from observations.
- 4.P.4A.5: Plan and conduct scientific investigations to explain how light behaves when it strikes transparent, translucent, and opaque materials.
- 4.P.4B. Conceptual Understanding: Sound, as a form of energy, is produced by vibrating objects and has specific properties including pitch and volume. Sound travels through air and other materials and is used to communicate information in various forms of technology.

- 4.P.4B.1: Plan and conduct scientific investigations to test how different variables affect the properties of sound (including pitch and volume).
- 4.P.4B.2: Analyze and interpret data from observations and measurements to describe how changes in vibration affects the pitch and volume of sound.

The task was to design and build a game (i.e., artifact) for first grade students to introduce the science concepts. Students were scaffolded through the design process with activities that allowed them to explore and discover what makes a game good or engaging. Opportunities to collaborate within teams and with other teams were encouraged through challenge boards and testing troubleshooting sessions. Reflection formally took place three times during the process and at the end of the unit. The thirteen sessions are outlined in Table 3.3.

Major topics for sessions included deconstructing games, exploring sound and light energy, brainstorming and building games, and testing, finalizing and reflecting. Each of these is discussed in further detail below.

Table 3.3. *List of Sessions and Activities for Game Design-Based Learning*

Sessions 45 minutes each	Activities and Timeframes
1	Introduction to purpose and goals for the game design-based learning (5 mins) Brainstorm what elements need to be present for something to be considered a game. (35 mins)
2	Deconstructing a video game (15 mins) Establishing Scratch logins for individuals and teams and exploration of the Scratch Platform (25 minutes)

Table 3.3. *List of Sessions and Activities for Game Design-Based Learning* Continued.

Sessions 45 minutes each	Activities and Timeframes
3	Exploring the science concepts of light and sound (15 minutes per Station) 3 light stations and 3 sound stations will be set up for students to explore the concepts of light and sound energy
4	Mini-Lesson/ Discussion defining creativity (5 minutes) Flow charting a game (20 minutes) GRASPS (Akcaoglu, 2013) (10 minutes) Students planning and designing game elements (15 minutes)
5-9	Mini-Lesson/ Discussion defining collaboration Introduce the Challenge Board (10 minutes) Division of tasks Building a game in the Scratch environment mockup and feedback session (20 minutes)
10	Testing games with 1st grade audience (30 minutes) Reflection (15 minutes)
11-13	Redesigning, finalizing, and reflection

Deconstructing Games

Students looked at popular or familiar games (e.g., Flappy Bird) to identify elements that they believed made a good game. This included characters, setting, storyline, conflict, and challenges (Baytak, 2009; Li, 2012; Foster, 2015; Rieber et al., 2001). GRASPS (Akcaoglu, 2013) was used to help students identify 1) goals, 2) rules, 3) assets, 4) spaces, 5) play mechanics, and 6) scoring. Flowcharts were introduced as a way for students to map simple if then elements within a game (Akcaoglu, 2013; Wang et al., 2016). For example, if a character bumps into an object then something will happen, earning points, losing points, or game over. Figure 3.1 presents an example flow chart that was used to introduce students to the concept. Students worked in small groups to deconstruct a game by filling out a sample flowchart and identifying elements.

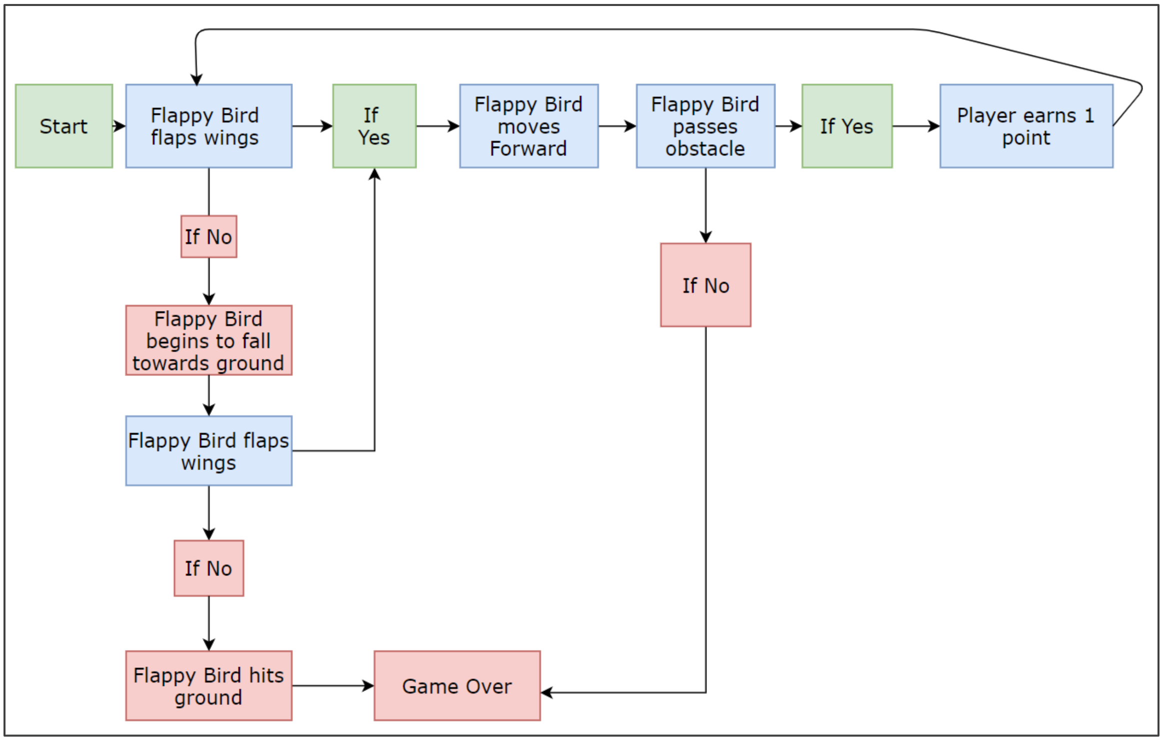

Figure 3.1. Example Flappy Bird flowchart

Exploring Light and Sound Energy

Session three involved an exploration of the light and sound energy concepts. This served as the anchor for the games the students developed. Light stations included using a prism to explore the spectrum of various light sources, modeling the concepts of reflection, refraction, and absorption of light, and experimenting with how light responds when it encounters transparent, translucent, and opaque materials. Sound stations included testing pitch and volume on various materials, exploring how sound vibrations travel through various materials, and measuring sound waves at multiple locations on the hallway (i.e. classroom, gym, hallway). This allowed students to begin thinking about what concept they would use to build their game around.

Brainstorming Ideas and Building Games

In session four, students began working with their teams to plan the elements of their game. They used the tools (e.g., flowcharts, GRASPS) from the deconstructing games lesson to guide their work. This stage involved creating storyline and exploring learning challenges that could be built into their game. Students were encouraged to narrow their topics to either light or sound concepts for presentation in their game. They also began making decisions about how to communicate these concepts to their target audience, first grade students.

Sessions five through nine were devoted to students working on their game projects. A “I have a question” board was introduced where students could pose a question about something that was challenging them in the design process. This was done through Padlet an online collaboration board. Students were given a brief introduction on how to post to the board and how to provide answers if they had them. QR codes and iPads were available for students to post questions and responses to the board. I monitored student questions for unresolved issues. At the beginning of each session I took a few minutes to review my notes with students for unresolved challenges. The goal was to have students responding to each other’s needs and working together to find solutions.

Testing, Finalizing and Reflecting

Session ten provided students in the opportunity to test their games with their target audience (Baytak, 2009). In this session, fourth graders observed first graders playing their games. They answered any questions the younger students had. The first graders were asked to provide feedback (Baytak, 2009) for the fourth-grade game designers.

The final sessions included implementing improvements based on information gathered from the test session with the first graders. Students finalized their projects and completed a reflection about their learning that they were invited to share with the whole group and play each other's games.

Data Collection

I used five data collection methods for this study. To gain insight to student perceptions and understandings of the game design-based learning experience, I looked at the following sources for data: 1) pre- and postsurvey, 2) pre- and posttest of science concepts, 3) collection of student design/ reflection journals, 4) video recordings, and 5) student focus group interviews. Each data source was aligned with a research question as shown in Table 3.4. All data were collected from the student participants in my class. Specific details about each source is discussed below.

Table 3.4. *Alignment Between Data Sources and Research Questions*

Research Questions	**Data Sources**
1) What kinds of problem-solving interactions occur during a game design-based learning science unit for fourth grade GT students at Cori Elementary School?	• Video observations of problem-solving interaction — checklist of problem-solving behaviors or activities — 45 minutes; five times per class • Student focus groups (interview protocol) • Reflection questions in Design Journals

Table 3.4. *Alignment Between Data Sources and Research Questions* Continued.

Research Questions	Data Sources
2) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their ability to be creative and innovative in science at Cori Elementary School?	• Pre- and postsurveys of student perceptions • Student focus groups (interview protocol) • Reflection questions in Design Journals
3) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their collaboration and teamwork skills in science at Cori Elementary School?	• Pre- and postsurveys of student perceptions • Student focus groups (interview protocol) • Reflection questions in Design Journals
4) Will game design-based learning improve knowledge of light and sound concepts for fourth grade GT students at Cori Elementary School?	• Pre-and Posttest

Pre- and postsurveys. Students (n = 36) competed a survey (see Appendix B) providing data on students' perceptions of their abilities in the areas of (a) creativity and innovation in science and (b) collaboration and teamwork. These skills are defined as World Class Skills that students will need to have in order to be college-and career-ready. The survey used a five-point Likert scale. There were 15 statements for creativity and 10 statements regarding collaboration for a total of 25 questions. Five items for creativity in science were adapted from Beghetto's (2009) survey on intellectual risk taking in science. These items were used to correlate with intellectual risk taking in science. The items have a reported reliability of $\alpha = 0.83$. The nine creative self-efficacy items were obtained from Brockhus et al.'s (2014) survey. These items were reported in conjunction with creativity assessment items. Since no reliability estimates were included with the instrument, a test of internal consistency (i.e., Cronbach's alpha) was computed after collecting data.

Collaboration items were developed from descriptions of collaborative behaviors observed by Ching and Kafai (2008) and Reynold (2016). These items were intended to measure student perceptions of their collaboration efforts in the game design-based unit. Internal consistency was computed after data collection.

Statements included the following items:

- I check with my team to make sure my work is accurate.
- I work with my group to identify goals for a project.
- My team shares the workload in a project.
- When I get stuck others help me by giving directions.

This allowed me insight to student perceptions of their strengths or weaknesses prior to the study and then allowed to me to look for changes after the game design learning unit. The information gained was descriptive in nature.

Pre- and posttest science concepts. Students (n = 42) took an objective pre- and posttest on light and sound concepts to ensure that the standards were being met. The science test (see Appendix C) was developed from a variety of assessments used by fourth grade teachers from two different schools. Each question was aligned with the state academic and performance standards for science (see Appendix D). A curriculum coach and the fourth-grade team at my school separately reviewed the test items and made recommendations to clarify wording and alignment. The information gained from this assessment helped make sure that the game design-based unit enhanced student learning.

Artifacts and design journals. Student journals provided insight to student thoughts on the process as well as their perceptions and experiences (Mertler, 2017). Student journals also provided me with valuable information grounded in the student's own words (Creswell, 201). Student design teams made up of three to four students kept electronic journals (Baytak & Land 2011; Khalili, 2014). These journals held their design documents, flow charts, and reflections on the process.

Through two mini-lesson sessions, students generated lists of behaviors associated with collaboration and teamwork; problem-solving; and creativity and innovation. These lists served as target behaviors and prompts to helps students work together. For example, a list of collaborative behaviors included help seeking, giving peer feedback, and sharing expertise (Baytak, 2009; Guo & Woulfin, 2016; Resnick, 2014, 2017). Students recorded periodic reflections (see Appendix E) in response to a prompt covering one of these areas. Below is one of the writing prompts.

> Describe a time when you and your teammates did not agree on how to proceed with your project.
>
> - What did you disagree about?
> - Why did you disagree?
> - How did your behavior change when they did not agree with you?
> - What information did you use to solve the problem?

I also included an opportunity for students to do a broader reflection (see Appendix E) that included more than one area of interest. An example of the general prompt asked students to:

- Share your thoughts on your growth in creativity, collaboration or problem-solving.
- Describe a point in this project when you felt you were able to solve a challenging problem.

Students record three reflections during the game design-based unit and one reflection at the close of the unit. This gave me insight to the students' perceptions and experiences of the game design-based learning unit in the classroom (Mertler, 2017). The reflections also revealed nuances that did not show up in the survey data. Having the students keep this type of record allowed them to look back at earlier responses and to be reflective on their growth and skills.

Observations. As a teacher in charge of the classroom, I needed to rely on semi-structured observations (see Appendix F) allowing me "the flexibility to attend to other events or activities occurring simultaneously in the classroom" (Mertler, 2017, p. 131). In some instances, I relied field notes to record the behaviors that I was interested in researching. This allowed me to check my observations with student perceptions. The checklist align with the behavior lists that students will be using in their journals. Items on the checklist included exploration of multiple possibilities (Beghetto & Karwowski, 2017), tinkering with materials (Resnick, 2007), testing boundaries, and taking risks (Resnick, 2014).

Video recordings. One group from each class was chosen at random to be the focus of video recordings that took place five times during the game design-based learning unit. These videos were 33-40 minutes long and provided me with information that I missed while attending to the needs of other students.

Kinash (2006) mentions turning recording equipment over to students. Empowering the students to record their work sessions helped me gain insight as to how the students worked together and how they solved problems within the group. This had the advantage of not being what I was doing to them but something they had control over. Kinash (2008) goes on to claim that students should be invited into the research process including reflection and revision. This type of data collection invites the students into the process. It allowed for data collection within the group and captured interactions I missed due to my role as a teacher.

All videos were analyzed using the Co-Measure Rubric (Herro et al., 2017) (see Appendix G). Co-Measure was developed to assess collaborative problem-solving during STEAM learning activities. The instrument is divided into four sections 1) peer interactions, 2) positive communication, 3) inquiry rich/ multiple paths, and 4) transdisciplinary approach. Peer interactions were measured by the following behaviors, 1) task monitoring and peer checking, 2) negotiation of roles, 3) division of workload, and 4) peer feedback and assistance. Positive communications are measured by the student's demonstration of respect for other's ideas, use of socially appropriate language, and listening and taking turns. Inquiry rich/multiple paths involves students developing appropriate questions and methods for solving problems and verifying information. Transdisciplinary approach is defined by negotiation of relevant methods or materials to solve a problem and using tools collaboratively.

The instrument has both rating scales for targeted attributes and space for observer notations. The rating scale for each targeted behavior includes needs work, acceptable, and proficient. Co-Measure was evaluated for construct validity by a panel of teachers and researches and it was found to be reliable through ratings of video examples of STEAM lessons.

Focus groups. The focus group interview allowed me to gather information about the various perspectives' students had on the game design learning unit. Table 3.5 shows the alignment between my research questions and my focus group questions. I gained much from this type of data collection because the parameters of group discussion were familiar to the students. My students were used to energetic discussions about other academic areas, for example literature circles or history debates. Students often feed off each other's ideas or present a counterpoint (Mack, Woodsong, MacQueen, Guest, & Namey, 2005).

I met with the focus group consisting of seven students four from one class and three from the other. The focus group session lasted 48 minutes and 12 seconds. The focus group session was audio recorded. I used the recordings to create a transcript that was analyzed for patterns and insights. The focus group took place at the end of the game design unit.

Table 3.5. *Alignment of Focus Group Questions with Research Questions*

Research Questions	Focus Group Questions
1) What kinds of problem-solving interactions occur during a game design-based learning science unit for fourth grade GT students at Cori Elementary School	• How did your group handle problems that arose while working on your game design? • Do you feel like everyone had a voice in the process? • Did all ideas get heard and considered? • How did you finalize your solutions?

Table 3.5. *Alignment of Focus Group Questions with Research Questions.* Continued

Research Questions	Focus Group Questions
2) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their ability to be creative and innovative in science at Cori Elementary School?	• Do you feel like you were able to be creative with your game design? • Tell me about something you created that you are proud of. • Do you think it is good to be creative in science/STEAM? Why or why not?
3) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their collaboration and teamwork skills in science at Cori Elementary School?	• Why is collaboration important in science? • Do you feel like your group collaborated on most issues? • Do you like participating in collaborative activities in STEAM? Why or why not?

Procedures and Timeline

The procedures for this research took place in four phases. Phase I included communicating with students and parents about the purpose and plan for research as well as obtaining consent for participation. This phase also included gathering pretest and presurvey data. Phase II involved the implementation of game design-based learning and collection of data. Phase III involved gathering post innovation data including postassessment, postsurvey, final reflections, and focus group interview. Phase IV focused on data analysis. Table 3.6 below provides a timeline and roles for both participants and researcher.

Table 3.6. *Data Collection Procedures*

Stage	Participant's Role	Researcher's Role	Time Frame
Phase I: Participant identification and pre-assessment data collection	1. Turn in consent forms 2. Take the Light and Sound Pre-Assessment 3. Complete the perceptions survey on creative and innovative and collaboration and teamwork in science	1. Provide students and parents with information about my research 2. Provide consent forms 3. Preassessment light and sound concepts 4. Survey of perceptions of their ability to be creative and innovative and collaboration and teamwork in science	2 weeks
Phase II: Innovation and Data Collection	1. Maintain a design journal that includes reflection question responses after sessions 3, 6, and 9. 2. Complete game based on knowledge of light or sound concepts	1. Observations of problem-solving interaction — checklist of problem-solving behaviors or activities 2. Provide design journals and guidelines 3. Select representatives to participate in focus group 4. Set up video recording for sessions 5-7	Thirteen 45-minute sessions Focus group took place at a different time than student work sessions.
Phase III: Post Innovation Data Collection	1. Post-assessment light and sound concepts 2. Post survey of perceptions of their ability to be creative and innovative and collaboration and teamwork in science	1. Provide instructions for completion of the post assessment 2. Provide instructions for completion of the post survey 3. Conduct focus group interview after session 13	1 week
Phase IV: Data Analysis	None	1. Inductive analysis 2. Descriptive statistics 3. Paired *t*-tests	Fall of 2019

Phase I: Participant Identification and Pre-Assessment Data Collection

Phase I began in January of 2019. At this time parents of fourth grade GT students were contacted with information about the study, its purpose, and expectations for those who participate. Parents were asked to sign a consent form (see Appendix A) for their student to participate in the study. Once permissions were turned in, students took the light and sound concepts preassessment (see Appendix C) through Google Forms. Students also completed the survey (see Appendix B) regarding their perceptions of their ability to be creative and innovative in science as well as their abilities to work collaboratively and show teamwork.

Phase II: Innovation and Data Collection

Phase II began mid-January of 2019 and continued through the end of the school year. Data was collected during thirteen-45-minute sessions while the students were in their STEAM class. Co-Measure was used as an observational checklist (see Appendix F) to identify instances collaborative behaviors. The checklists were used after instruction while students are working in small groups on their game design projects. Journal reflections (see Appendix E) were collected after session eight, ten, and thirteen. Journal reflections asked students to comment on their perceptions of their ability to be creative and innovative as well as their perceptions of the collaboration process and how it was working with their group. Recorded observations took place during sessions six through ten. The recordings focused on one group in each class to track their progression and growth as a team. Once students completed their games, design journals and final copies of their projects were collected for review.

Phase III: Post Innovation Data Collection

Phase III was completed in late May. Students completed the postassessment (see Appendix C) on light and sound concepts. This was done through Google Forms during their regular class time and was assigned to them by their GT teacher. During this time, they also completed the postsurvey (see Appendix B) on their perceptions of their abilities to be creative and innovative as well as collaborative and teamwork skills. After the project was completed, seven students were invited to participate in a focus group interview (see Appendix G). This took place outside of class time during my planning period at a time that works for the students and their home base teacher.

Phase IV: Data Analysis

For qualitative data, analysis was ongoing throughout the duration of the innovation. Inductive analysis was used to uncover themes.

Quantitative data was analyzed after students completed postassessments and surveys. Descriptive statistics and paired t-tests were completed in the fall of 2019. Comparison and triangulation of data also occurred during the fall of 2019.

Rigor and Trustworthiness

To ensure rigor and trustworthiness of my research, I used the following methods: 1) triangulation, 2) audit trail, 3) member checking, and 4) peer review. Each method is explained below, along with a description of how it helped me as a researcher and how I accomplished each one within my study.

Triangulation is a process of comparing evidence from various sources to "build a coherent justification for themes" (Creswell, 2014, p. 251). In my study, I used the triangulation of survey data, which showed student perceptions of their thinking skills, with data obtained from observations that captured actual behaviors or demonstrations of these skills. I also included data from student design journals and focus group interviews to confirm both student perceptions and actions. Triangulation was an ongoing process as each new piece of data was obtained, the results were compared and merged with previously recorded data.

An audit trail allows other researchers or interested parties to follow the research process beyond just the data that were collected. The audit trail included a record of decision making as it relates to themes that emerged (Creswell, 2014; Shenton, 2004). Keeping a research journal with rich detail helped me to see how my understandings grew through the process of collecting and analyzing data. It provided a clear path from data points to themes. The journal also allowed me to circle back and check why, when, and how decisions were made.

Member checking was done with participants of the study to confirm and explain patterns that emerged from data collection (Shenton, 2004). This helped me to be sure that my understandings matched that of my students. Member checking allowed my students to clarify their thinking for me and to add insights as to why and how they were processing their learning. I involved students in member checking in small groups while reviewing student design journals and games and again at the end of analysis.

Peer debriefing was used to question the analysis and understandings that emerge from the research. It was a reflective process that involved questioning and critiquing processes, analysis, and interpretations (Mertler, 2017) and enhanced the accuracy of the account (Creswell, 2014). This was an opportunity to dig deeper into the data that had been collected and analyzed. This helped to ensure that the conclusions I reached were not clouded by researcher bias. Peer debriefing occurred with the help of my dissertation advisor.

Plan for Sharing and Communicating Findings

Sharing this process began with my students and was ongoing through the stage of analysis and writing. I saw their reflections as an important piece of my work and their growth. At the end of our work, I would like for us to share not only the artifacts that students created but also their reflections as mirrored by my findings. This will be done at the school on our STEAM showcase night. I would also make more formal information available to parents and others through my website. I am a member of our district's technology professional learning community. We meet periodically to share and plan. These meetings are often attended by district office personnel. I plan to share my findings with this group of teachers and administrators.

In addition, both state and national gifted conferences would be appropriate places to share my work. The state Consortium for Gifted Education holds an annual conference that is attended by teachers, coordinators and administrators from across the state. The National Association for Gifted Children hosts a similar conference on the national scale. Finally, my state's Association for Educational Technology and the Association for Educational Communications and Technology both offer avenues to share what I have learned. I protected my participants' identities by changing names for any direct quotations that were used and by not using any identifiable descriptors.

CHAPTER 4

ANALYSIS AND FINDINGS

The purpose of this action research was to describe the impact of digital game building on fourth grade GT students' growth in problem-solving, creativity, collaboration, and science content knowledge at Cori Elementary School. Both quantitative and qualitative data were collected to answer the following questions: 1) What kinds of problem-solving interactions occur during a game design-based learning science unit for fourth grade GT students at Cori Elementary? 2) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their ability to be creative and innovative in science at Cori Elementary School? 3) In what ways will a game design-based learning unit impact fourth grade GT students' perception of their collaboration and teamwork skills in science at Cori Elementary School? 4) Will game design-based learning improve knowledge of light and sound concepts for fourth grade GT students at Cori Elementary School? This chapter will begin with the analysis and findings of the three quantitative sources followed by analysis and findings of the four qualitative sources.

Quantitative Analysis and Findings

This study included three quantitative data sources. The three assessments include 1) Creative Self-Efficacy Survey, 2) Collaboration Survey, and 3) Sound and Light Science Test. Pre- and postassessments were given for each. This section will cover the results of each assessment, including descriptive statistics and levels of significance. For the Sound and Light Science Test and the Collaboration Survey, nonparametric tests (i.e. Wilcoxon sign rank) were applied due to deviation from normality. These nonparametric results are presented, as well.

Creative Self-Efficacy Survey

The creativity survey addressed both creative self-efficacy in science and creative self-efficacy. The results are discussed separately. Of the 46 participants, 36 students completed the pre- and postsurvey. These 36 pairs of scores were used for analysis. Ten students' scores were removed prior to analysis. Seven students did not complete the postsurvey. One student moved to a different school and did not complete the study. One student took the presurvey multiple times with varying answers and another did not take the presurvey. These students' scores were removed prior to analysis.

Creative self-efficacy in science. The creativity portion of the survey consisted of 15 items that were assessed on a five-point Likert scale. Five items were adapted from Beghetto's (2009) survey on intellectual risk-taking in science. These items center on creative self-efficacy in science and had an established reliability of Cronbach's alpha = .83 (Beghetto, 2009). The reliability of the creative self-efficacy in science items were tested with the posttest (*n* = 36). The Cronbach's alpha for these items was .71 which falls in the range of respectable (DeVellis, 2003). The remaining items were from Brockhus et al.'s (2014) questionnaire on creative self-efficacy. These items cover general creative self-efficacy. The reliability of these items was tested with the posttest (*n* = 36). The Cronbach's alpha for these items was .81 which is considered very good (DeVellis, 2003).

Descriptive statistics for the creative self-efficacy in science portion of the survey are presented in Table 4.1. Individual student scores were totaled to create one score for the five items with a possible score of 25. Students' creative self-efficacy decreased from presurvey (*M*= 19.56, *SD*=3.04) with a range of scores between 11 and 25 to postsurvey (*M*= 19.36, *SD*=2.84) with a range of scores between 14 and 24.

For both the presurvey and postsurvey, all means were above 3.5. This reflects overall positive creative self-efficacy in science for this group of students. Item 7 had the highest variance as evidenced by standard deviations of 1.09 for the presurvey and 1.07 for the postsurvey. The Shapiro-Wilk test revealed no deviation from normality.

Table 4.1. *Mean and Standard Deviation of Creative Self-Efficacy in Science Items (n = 36)*

	Presurvey		**Postsurvey**	
Survey Items	***M***	***SD***	***M***	***SD***
2. I am good at coming up with new ideas during STEAM class.	4.06	0.83	3.89	0.79
4. I have a lot of good ideas during STEAM class.	3.91	0.87	3.75	0.81
6. I am good at coming up with new ways of finding solutions to science problems.	3.53	0.74	3.81	0.71
7. I am good at coming up with my own science experiments.	3.69	1.09	3.67	1.07
9. I have a good imagination during STEAM class.	4.36	0.76	4.25	0.77
Totals	19.56	3.04	19.36	2.84

A paired samples *t*-test was conducted to compare the totaled means from creative self-efficacy in science presurvey to postsurvey. The results showed no significant difference from presurvey (*M* = 19.56, *SD* = 3.04) to postsurvey (*M* = 19.36, *SD* = 2.84), $t(35) = 0.40$, $p = 0.693$.

Creative self-efficacy. Descriptive statistics for the creative self-efficacy portion of the survey are presented in Table 4.2. Individual student scores were totaled to create one score for the ten items with a maximum possible score of 50. Individual scores ranged from 24 to 47 on the presurvey and 29 to 48 on the postsurvey. The mean score for the presurvey was 38.44 with a standard deviation of 4.19. The postsurvey mean was 39.25 with a standard deviation of 4.85.

Table 4.2. *Mean and Standard Deviation for Creative Self-efficacy Items (n = 36)*

	Presurvey		Postsurvey	
Items	***M***	***SD***	***M***	***SD***
1. I am a creative person.	4.31	0.75	4.42	0.65
3. When I am confronted with a problem, I can usually find several solutions.	3.50	0.74	3.72	0.70
5. I trust my creative abilities.	4.33	0.93	4.28	0.94
8. I am good at solving complicated problems.	3.69	0.82	3.64	0.83
10. I can solve problems skillfully, even complicated problems.	3.44	0.77	3.47	0.65
11. Compared to my friend, my ideas are outstanding.	3.33	0.72	3.39	0.99
12. Many times, I proved I can find at least one solution for any difficult situation.	4.14	0.87	4.14	0.72
13. I can deal with problems requiring creative thinking	4.22	0.83	4.28	0.70
14. I am good at proposing "out of the box" solutions.	3.81	0.89	3.97	0.81
15. I am confident that I can develop creative ideas for almost any problem.	3.67	0.83	3.94	0.92
Totals	38.44	4.19	39.25	4.85

The largest gains were in Item 15: "I am confident that I can develop creative ideas for almost any problem," (Gain = 0.27), Item 3: "When I am confronted with a problem, I can usually find several solutions," (Gain= 0.22), Item 14: "I am good at proposing "out of the box" solutions," (Gain= 0.16) and Item 1: "I am a creative person," (Gain = 0.11). Item 1: “I am a creative person,” had the highest postsurvey average of 4.42. Item 5: “I trust my creative abilities,” and 13: “I can deal with problems requiring creative thinking” also had high postsurvey averages of 4.28. The Shapiro-Wilk test revealed no deviation from normality.

A paired samples *t*-test was conducted to compare the totaled means from presurvey to postsurvey. The results showed no significant difference from presurvey (M = 38.44, SD = 4.19) to postsurvey (M = 39.25, SD = 4.85) $t(35) = 1.24$, $p = .224$.

Collaboration Survey

The items for the collaboration section of the survey were developed from descriptions of collaborative behaviors observed by Ching and Kafai (2008) and Reynolds (2016). These items measured student perceptions of their abilities to work collaboratively within the game design-based unit. Like the Creative Self-efficacy survey, the number of participants was 36. The reliability of the collaboration items was tested with the posttest data (n = 36) for the 10 items. The initial Cronbach’s alpha for these items was .67 with Item 16 reversed. Two items (i.e., Items 20, 23) were removed from the instrument in order to increase the reliability. The reliability with the remaining eight items was .702 falling into the respectable range for reliability (DeVellis, 2003) Therefore, these eight items were used for the rest of the analysis.

For the collaboration portion of the survey, individual student scores were averaged across the 8 items to create a single score. The mean of the presurvey was 3.49 with a standard deviation of 0.36 and a median of 3.40. The mean of the postsurvey was 3.58 with a standard deviation of 0.44 and a median of 3.60.

Table 4.3 presents the results for individual questions in the survey. For the presurvey, the mean scores ranged from 2.11 to 4.19. The postsurvey scores ranged from 2.25 to 4.19. Item 18 was the lowest scoring item for both the pre- and postsurvey with mean scores of 2.11 and 2.25 respectively. The highest scoring item for the pretest was Item 25 with a mean of 4.19. The postsurvey mean for this item was also a 4.19. The largest mean gains were in Item 16 (Gain = 0.28), Item 22 (Gain = 0.28), and Item 24 (Gain = 0.25). Item 21: "I work with my group to identify goals for a project," Item 23: "My team relies on each person's skills," and Item 25: "I check with my team to make sure my work is accurate" had the highest postsurvey averages at 4.19. Item 24: "My team shares the workload in a project" was also high with a mean of 4.17.

Table 4.3. *Descriptive Statistics for Collaboration Pre- and Postsurvey (n = 36)*

	Presurvey		**Postsurvey**	
Collaboration Items	***M (SD)***	***Mdn***	***M (SD)***	***Mdn***
16. When I have a problem or get stuck, I try to work it out by myself. *	3.11 (1.24)	3	2.83 (1.00)	3
17. When I get stuck on a challenge, other members of my class help me by giving me directions.	3.44 (0.91)	3.5	3.42 (0.91)	4
18. When I get stuck, others step in and fix the problem for me.	2.11 (0.85)	2	2.25 (1.08)	2
19. When others get stuck, I help by giving directions.	4.06(0.79)	4	3.83 (0.78)	4
21. I work with my group to identify goals for a project.	4.08 (0.94)	4	4.19 (0.82)	4
22. I work with my team to monitor our progress on a project.	3.69 (0.75)	4	3.97 (1.00)	4
24. My team shares the workload in a project.	3.94(0.86)	4	4.17(0.85)	4
25. I check with my team to make sure my work is accurate.	4.19 (0.75)	4	4.19 (0.92)	4
Totals	3.49 (0.36)	3.40	3.58 (0.44)	3.60

* *Note.* Item16 was reversed for the analysis.

Dependent *t*-tests were planned for comparing presurvey and postsurvey data for collaboration. After tests for normality (i.e., Shapiro-Wilk), the data were determined to be non-normal. Thus, the non-parametric Wilcoxon signed-rank test was conducted for paired pretests and posttests. The output indicated that postsurvey scores (Mdn = 3.60) were significantly higher than presurvey scores (Mdn = 3.40), Z = 2.082, p = .037.

Light and Sound Science Test

Of the 46 participants, 42 students completed both the pretest and posttest. Each item on the instrument was aligned with state academic standards and performance indicators for science. The instrument was reviewed by two content experts for validity. The reliability of the instrument was tested with the posttest data (n = 42) for the 18 items. The Cronbach's alpha for the instrument was 0.70 which falls into a respectable range (DeVellis, 2003).

Descriptive statistics for the Light and Sound Pre-Post Test scores are recorded in Table 4.4. The pretest scores had a range from 4 to 18 with a mean of 13.45 and a standard deviation of 3.20. The median for the pretest was 14.00. The posttest scores range from 11 to 18 with a mean of 16.00 and a standard deviation of 1.71. The median for the posttest was 16.00.

Table 4.4. *Descriptive Statistics for Light and Sound Pretest and Posttest (n=42)*

	M	***SD***	***Mdn***
Pretest	13.45	3.20	14.00
Posttest	16.00	1.71	16.00

Dependent *t*-tests were planned for comparing pretest and posttest data. However, after tests for normality (i.e., Shapiro-Wilk), the data were determined to be non-normal. Thus, the non-parametric Wilcoxon sign-rank test was conducted for paired pretests and posttests. The output indicated that posttest scores (*Mdn* = 16.00) were significantly higher than pretest scores (*Mdn* = 14.00), $Z = 5.02$, $p < .001$.

Qualitative Analysis, Findings, and Interpretations

Qualitative data sources included a focus group interview, student reflection prompts, game design documents, games, and video recordings. The focus group included seven students and lasted 48 minutes and 12 seconds. Reflection prompts were given throughout the study covering creativity, collaboration, and problem-solving. The final reflection allowed students to reflect on each of these areas. Game design documents for each group showed the students' planning for their games. The focus group interview was transcribed verbatim and all quotes from the interview, student reflections, and design documents are in the students' own words to ensure authenticity. Student games were not coded but were used to connect student reflections to their artifacts. Video recordings were used to generate observations about student actions and words. Table 4.5 shows the numbers for each source and the number of codes that were applied to each. This section covers 1) analysis of qualitative data, and 2) themes.

Table 4.5. *Summary of Qualitative Data Sources*

Types of Qualitative Data Sources	Number	Total Codes Applied
Focus group interview transcript	1	155
Student Reflections		
Creativity	43	102
Collaboration	20	40
Problem-Solving	42	129
Final Reflection	42	107

Table 4.5. *Summary of Qualitative Data Sources.* Continued

Types of Qualitative Data Sources	**Number**	**Total Codes Applied**
Game Design Documents	15	112
Student's Games in Scratch	15	
Videos of student groups working 5 per class 30-45 minutes each	10	231
Totals	188	876

Analysis of Qualitative Data

The focus group interview was uploaded to Temi, an online transcription service. After the initial transcription, I listened to the interview and made edits and clarifications to the transcript. Student reflections and game design documents were typed by the students and shared with me through Google Classroom. Qualitative analysis was approached through inductive analysis (Mertler, 2017), and coding was done sentence-by-sentence using Delve, an online coding and analysis tool. A first round of coding began with structural coding (Saldaña, 2016), where labels were placed on larger chunks of data relative to the study's specific research questions. Labels included *problem-solving*, *creative self-efficacy*, *collaboration*, and *sound and light science concepts*. This was applied to student reflections, field notes, and the focus group interviews. Structural coding was followed by in vivo coding (see Figure 4.1) to capture student voice and process coding (see Figure 4.2) to capture the actions students were taking (Saldaña, 2016), for example *think together, try out something new,* and *big ideas.* In coding students' final reflections, some versus coding (Saldaña, 2016) emerged as students reflected on their growth throughout the unit. These codes included *alone vs. team, ideas vs. time*, and *simple vs. complex coding.*

Figure 4.1. Screenshot from Delve showing in vivo codes applied to student responses.

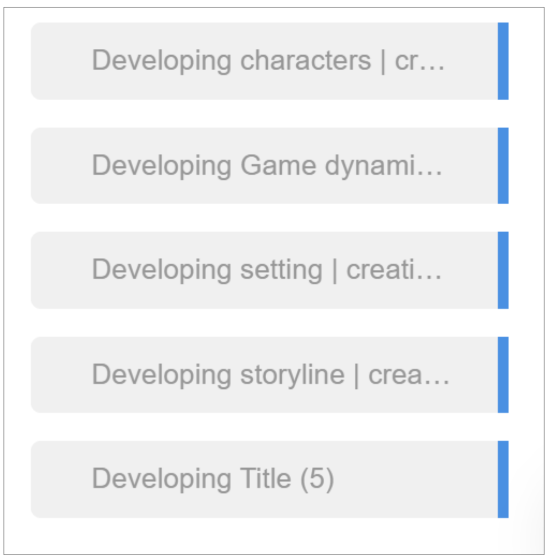

Figure 4.2. Examples of process coding.

Pattern coding was applied to reflections and the focus group interview transcript and used for second round coding. This allowed for both the organization of the data and the development of themes from the original codes (Saldaña, 2016). Codes were also downloaded from Delve to Microsoft Excel to allow for sorting and managing codes.

Due to the “fluid and dynamic nature of qualitative analysis” (Corbin, 2009. p. 41), I used paper, pencil, and highlighters to help reveal connections between categories and to develop themes. See Figure 4.3.

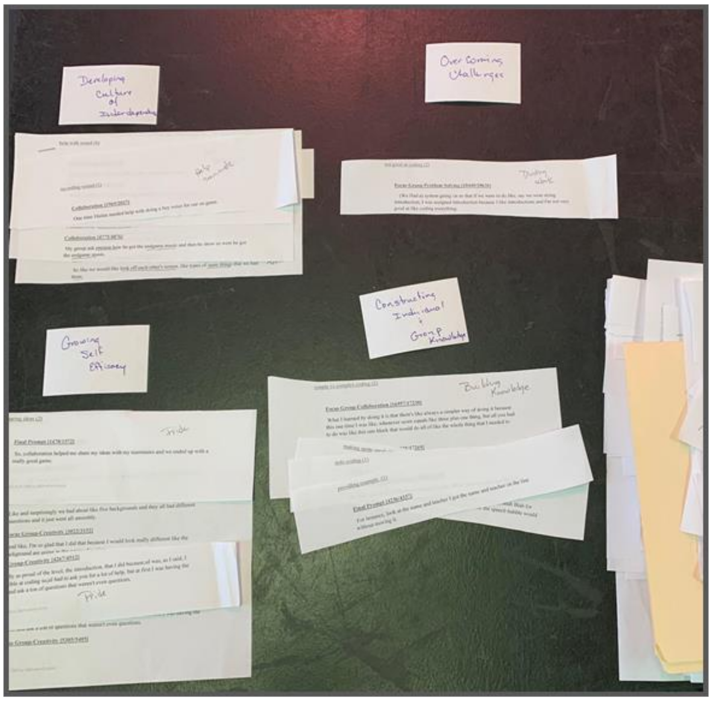

Figure 4.3. Photograph of sorting codes into categories.

Coding of student game design documents started with specific questions in mind. I was looking for story elements, game elements, mention of science concepts, and integration of science content into story. Story elements included storyline, characters, setting, and challenges faced. Game elements included levels, mechanics of play, and scoring or rewards for progress. If students identified a science concept in their document, it was coded as being present. If content was woven into the storyline, it was coded as having connections to the storyline. Table 4.6 shows game elements and number of codes that were applied for the fifteen game design documents.

Table 4.6. *Codes from Game Design Documents*

Element presented in student design documents	**Number of times codes were used**
Storyline	8
Characters	15
Setting	9
Challenge	20
Levels	14
Rewards or scoring	12
Science content identified	16
Science content connected to storyline	7
Space/Setting	12
Rewards/Scoring	12
Total Codes	125

Videos were analyzed with the elements of CoMeasure (Herro, et al., 2017) as a focus for interpretation. Notes were taken on student actions and interactions. There were 10 videos ranging from 34-40 minutes in length. These observations were then coded using elements from CoMeasure section on Peer Interactions. These included 1) monitoring task with peers, 2) division of work, and 3) providing feedback through positive communication. See Table 4.7. Video observations also provided an opportunity to confirm some of the categories that emerged from student reflections. These included *design thinking*, *expressions of pride*, *information seeking*, and *information sharing*.

Table 4.7. *Codes from Video Observations*

Codes from Video Recordings	**Number of Codes**
Monitors tasks with peers	98
Seeking information	23
Sharing information	23
Switching seats or devices	38
Troubleshooting	12
Division of work	10
Positive communication/ feedback	14
Design thinking	30
Expressions of pride	11
Totals	259

Through the process of peer debriefing with my dissertation advisor, two topics were raised for further analysis: a) science content, and b) coding. I went back to the data to look at how science was incorporated into the game design process and what students had to say about coding in the Scratch environment. In looking at the data through these lenses, I was able to get a fuller picture of all of the aspects of this study.

Member checking occurred throughout the data collection and analysis process. I checked with students to clarify what they meant in their reflections. For example, two students used the term *popular sovereignty* in their reflections on problem-solving, I checked in with each of them to verify what they meant by this and what their process was for reaching consensus. Once all themes were established and the analysis was written up in draft form, I invited two students to a lunch meeting in my classroom to discuss my analysis. They were in agreement about the findings with the exception of challenges in the game design process. Both of their games fully integrated science and narrative, so I decided to invite more students in to discuss my findings. Six additional students were asked for their input, particularly around the issue of integrating the narrative of the game and science content. We met as a group for about 15 minutes during one of my free periods. All of them agreed that this was a challenge for their groups, but they felt like through working together and combining ideas, they were able to complete their games.

Themes

Themes emerged as I looked at the data through various lenses. In order to get a full picture of what the game design-based learning experience meant to my students, I had to think about the impact of their giftedness, the study's purpose to incorporate game design and science, and the impact of coding on students' perceptions of their abilities to problem-solve, create, and collaborate. The following five theme evolved from the data: 1) overcoming the challenges of group work, 2) developing a culture of collaboration, 3) creating narrative and connecting science content 4) problem-solving in the coding environment, and 5) reflecting on learning. Themes were ordered and numbered to best tell the story of the game design-based learning experience in my classroom. Themes and their associated categories are presented in Table 4.8. Each theme is discussed in detail below.

Table 4.8. *Summary of Themes and Categories from Qualitative Data*

Theme	Categories
1. Overcoming the challenges of group work	• Reinforcing the need to work in teams due to task complexity • Distributing work equitably among group members • Managing a project
2. Developing a culture of collaboration	• Encouraging the emergence of student expertise • Growing security in seeking help from peers
3. Designing games	• Crafting narrative elements • Incorporating science concepts
4. Problem-solving in the coding environment	• Tinkering • Pushing boundaries • Troubleshooting
5. Reflecting on learning	• Coping with project constraints • Defining and enacting creativity • Developing self-efficacy in collaboration • Expressing pride in work that was completed

Theme One: Overcoming the Challenges of Group Work

Group work presents a unique challenge for GT students (French, Walker, & Shore 2011; Kanevsky, 2015). Their personalities and mindsets often create more challenges when it comes to working collaboratively (Mofield & Peters, 2018). Traits like heightened emotion (NAGC, 2019), task commitment (Subotnik et al., 2011), and perfectionism (Mofield & Peters, 2018) are often impediments to successful group dynamics. Group work requires shared responsibility (P21, 2009), searching out, organizing and distributing responsibilities (Kafai & Burke, 2014). GT students respond positively to group work when they are

participating in a task that is challenging, complex, and requires multiple people to complete (Diezmann & Watters, 1997; Lou et al., 2001; Ross & Smyth, 1995;

Winstanley, 2010) and when there is an equitable distribution of workload (Salomon & Globerson, 1989).

When the game design-based learning project was introduced, students had typical questions and complaints about having to work in groups. Many students were concerned about who they would be partnered with for the project. One student asked if the class could give me a list of who they wanted as partners and several students requested that they be allowed to work on their own. In the beginning, there were several arguments among group members who had very definite ideas of what the project should look like. Students clashed over things like themes, storyline, and game mechanics. Students needed to learn to work together, communicate and compromise. Three categories support the theme of overcoming the challenges of group work 1) Reinforcing the need to work in teams due to task complexity, 2) Distributing work equitably among group members, and 3) managing a project.

Reinforcing the need to work in teams due to task complexity. The task of designing and building a computer game for first graders offered a challenging and complex task for fourth grade GT students to undertake. Game design involves thinking about the game as a system and planning for user inputs, crafting narrative, and for my students, incorporating science concepts. Unlike work that could easily be done by one person, the game design project involved students in a project that lasted thirteen class periods spread out across an entire semester and had several parts that needed to be completed. At one point, Britanie asked if her group could work during their recess time she stated, "This is harder than I thought it would be." The authenticity and the volume of the project (French et al., 2011) helped students to realize that they needed to depend on each other to accomplish their goals. Students grew to understand that the work they were doing could not be accomplished by one person in the timeframe that we had. This understanding helped students overcome some of their negative feelings about working in groups. The following student reflections indicate their understanding of the need to work in teams to accomplish big tasks. Students also wrote about working across teams to complete their games.

Erin: We needed a teamwork kind of help. If it was just one person, we would have never finished anything. I needed help from Brenna when we did not know how to do the questions. I helped Hannah's group come up with an idea for the base of their game. Brenna's group also showed me and Rachel how to make a text box appear when they click the question, also how if you get it right, you move on. If you get it wrong, then you try again until you get it right.

Diego: I used my collaboration with others when my group had to fix something, but it required multiple people, so we collaborated.

Jacob: I grew in collaboration the most because I used to not work well with others and this project made me realize with something like this, I need others.

Mira: My collaboration with other[s] helped. When we were coding, we had things to do and to make it perfect. Me and Shreya helped each other by having us exchange work so she does the part that was hard for me and I do the part that she didn't know.

Parker: Our group depend[ed] on each other.

The students responded positively to the task of designing and building a game. The complexity of the project led students to an understanding of and an appreciation for working as a team. They relied on each other to fix coding issues, recognized each other's strengths, and expressed their understanding of the value of working together. At the beginning of the new school year, many of these students asked if they could work in teams again this year.

Distributing workload equitably among group members. Equitable distribution of work means that each student is responsible for the same amount of work. In many situations, GT students are expected to carry the heavier burden for completing group work, this can leave students feeling used and angry (Patrick, Bangel, Jeon, & Townsend, 2005). This inequity can lead students to dislike resent working in a group thus making it more challenging to get students to feel like group work will be worth their efforts. When the game design-based learning project was introduced, Britanie complained about having to work in a group, stating, "My teams at school, I do all the work. My teams outside of school, we share the work." For group work to be effective, workload should be equally shared (Salomon & Globerson, 1989) and all members of the group should be equally committed to the task. During the focus group discussion, most of the students complained about a team member or someone from another team who was off task and distracting to the other students. For example, Steven shared, "I feel like the hardest part in my group was that Brenna and Ayden were sometimes, like, looking at other things. Like, they were looking at music, or they were talking to friends at another table." Many of these behaviors centered around using the *Add Sound* feature in Scratch and were focused on a few students in each class. The majority of the groups were able to share the workload and complete the games. In their reflections, students described their successes and how they divided the work. They wrote:

Hannah: A time when me and my partners made a creative solution to a problem was when we couldn't find out how to split the work up between us. We made a solution by finding out everyone's strengths and weaknesses so everyone could work on what they were good at. For example, I am good at coding sprites and telling them what to do, so we decided I would work on the intro.

Ankita: So, Khloe had [the] introduction because she had level one, Kumari had level two, and I had a level three. Tyler had level four.

Eli: We eventually figured it out that they would work on the first floor and I would do the second. Now we have to figure out which one of us is going to do the third.

Equitable distribution of work was important to students as they completed their games in teams. Students used levels within the game to separate the workload. They also made decisions based on skills and preferences. Sharing the work helped students overcome their initial hesitation about group work because they felt like equal partners in the project.

Managing a project. This category encompassed student statements of how planning and managing a project were important to their collective group work. The challenges for managing the group project were primarily described within two topics.

First, the students described how creating, using, and managing a project plan were important to their project's completion. For example, Katie described the importance of having a plan: "It's like putting together a puzzle; if we didn't have the right pieces, it wouldn't all put together." Students knew from the beginning that developing their plan was important. For example, one group put aside their computers and drew a map of what they wanted their game to look like. Rishi described the importance of this drawing: "So, then, everyone in the group got the idea, and we all knew what we were doing from the start because we had a picture in front of our seats." Another group set aside their devices in order to focus on coming up with a plan. After the group had discussed their ideas, they agreed on who would work on the design document and who would be in charge of the game flowchart. Changing the plan without the agreement of the group caused frustrations. While having a plan was important, some students pointed out the importance of being willing to change plans. For example, Sam wrote, "So our plan was to do, like, a door ... in order to escape, but there can't be a door in the middle of the jungle." This indicates a recognition of the necessity of changing plans with growing ideas.

Second, the students described how communications within their group was essential to overcoming the challenges of working within their groups. Herro et al. (2017) identified contributing ideas and compromising as specific issues within STEAM projects. In establishing their groups' plans, students had to maintain communication in order to keep their projects moving forward. Maintaining communication required students to regularly check in with each other and come to an agreement on how to continue with their projects. Communication is an important part of group work and students who do not successfully engage in maintaining communication have a difficult time managing projects, for example, Brayden described the results of his team not communicating: "The third part was completely different from what we were doing. Like, he [one of his partners] had these other characters and different backgrounds and different, like, ways of doing it." Student reflections emphasized the importance of sharing ideas and compromising. Students wrote:

Katie: We decided at the end to put both ideas together to create one big idea that includes everyone's suggestions.

Sebastian: Eventually we mixed our ideas and became a better team.

Madison: We compromised, and we did my idea for this one [level of the game], Kevin's for another, and Katie's last.

Hunter: The Information we used was a compromise to [where] the people I wanted to be good was evil and had powers. The person that my teammates wanted was good but with no powers.

Khloe: My behavior changed when they did not agree with me because I started to think that there was something else, we could come together on. Lastly, we decided to take both ideas and turn them into one.

Katie: So, you have to tell each other, we're working on this and make an idea and then put it together.

Providing my students opportunities to discuss with each other where they were in the project at the beginning of each session helped them communicate throughout the project. These group communications also contributed to successfully (or unsuccessfully) managing their project plans and working within their groups.

Summary of Theme One. While group work typically is challenging for GT students, the game design-based learning experience provided my student with an opportunity to successfully engage in group work that required shared responsibility. Game design-based learning provided a complex task where students needed to work in teams to accomplish their goal. The majority of student found ways to distribute the workload in an equitable manner. Students were able to gain skills in managing a project and maintaining communication with their design teams.

Theme Two: Developing a Culture of Collaboration

For GT students to work effectively in groups a culture of collaboration needs to be built in the classroom. For my students this meant accepting collaboration as part of our classroom culture where seeking, sharing, and testing knowledge were embraced as norms. Teacher supported collaborative processes allow students to work together to construct knowledge (Ertmer & Simmons, 2006; Hmelo-Silver, 2015). Through overcoming the challenges of group work, as discussed previously, students were able to participate in shifting the culture of the classroom. Students had the opportunity to develop and share their growing expertise in coding and game design. Through student reflections, focus group responses, and observations, two categories developed from the data; a) encouraging the emergence of student expertise in coding and b) security in seeking help from peers.

Encouraging the emergence of student expertise in coding. Classroom culture of collaboration encourages development of student experts, where students access information "just when it needs to be explored or to help in completing some kind of process or activity" (Khalili, 2014 p. 20). In this environment, students felt free to ask for help not only from the teacher but also to seek out help from peers. Distributed expertise (Baytak, 2009) as part of collaborative learning represents a role shift for students and is different from peer tutoring in that the GT individual is not called upon by the group to have all of the answers (French et al., 2011). Distributed expertise allows students to develop expertise in one or more areas, for example in game design-based learning, students could master coding in sound, or motion, and then they are able to share the part they know and do well with others in the class. Student learning is driven by questions or issues that they identify and explore for the purpose of moving the project forward (Patrick, Bangel, Jeon, & Townsend, 2005). "Game design affords opportunities for self-directed learning or upskilling through observation, imitation, and peer teaching at the point of demand" (Baytak & Land, 2011 p. 775). This involves an ownership of the knowledge that has been gained, as well as the understanding of its benefits to others. Figure 4.4. illustrates the emergence of expertise as students sought new information, built and tested code, and then shared information with their peers. Each student had an entry point into the process whether it was seeking solutions from peers or seeking information from outside sources such as Scratch tutorials or the Scratch Wiki. Students were able to practice their emerging expertise through building, testing, and sharing coding solutions. Students were able to participate in multiple ways as new experts emerged. This further illustrates that there was no expert class that arose within the class.

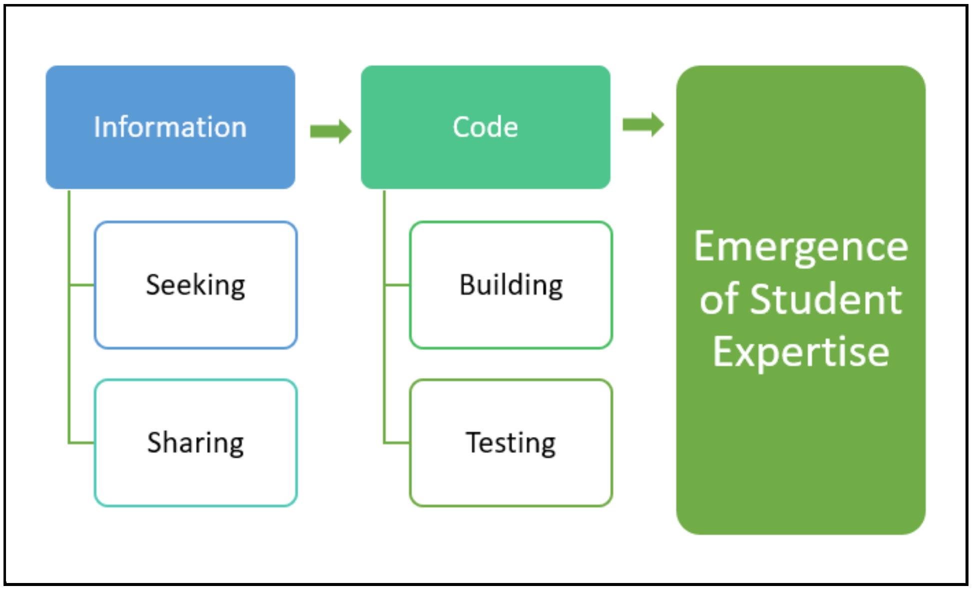

Figure 4.4. The emergence of student expertise as supported by information seeking and sharing as well as the building and testing of code.

Information Seeking. Information seeking deals with the way's students sought answers to their coding challenges. Information seeking connects to culture of collaboration because unlike traditional classroom settings students were expected to seek their own answers and then to share their knowledge with others. Each project was unique and required different pieces of coding information at different times. In our early design sessions, the line to ask me a question was rather long, and questions varied. As students realized that they could turn to other sources for information, the line got shorter. This gave students an opportunity to take ownership of their learning and seek the information they needed. Students gained an understanding of coding based on their vision for their group's project. This vision often created a dynamic tension (M. G. Jones, personal communication, May 27, 1995) between what they already knew and what they wanted to know. For example, one group decided early that they wanted their game to look and feel line Super Mario Brothers. They soon realized that I did not have step by step instructions to give them. This pocket of need created opportunities for student driven learning (Gentry, Renzulli, & Reis, 2014). As coding issues arose, students needed to find solutions to these issues ‘‘learning-on-demand’’ model (Kafai & Ching 2001). Three methods of seeking information or solutions to coding issues were documented by students. These include 1) searching within the Scratch environment, 2) remixing and 3) seeking help from peers. First, many students had used Scratch in the past and were familiar with the step-by-step tutorials that are available within the Scratch environment. Students accessed these tutorials and their past projects to refresh their knowledge of coding. In notes from the video observations, students were observed checking Scratch tutorials in three of the ten videos. Next, an example of remixing occurred with Hunter's group that spent three sessions seeking out and studying the code in games that were similar to what they wanted to create. They then completed a combination of copying and remixing the code for their game. Through this gathering of information, Hunter's group became experts on remixing. When other students needed to remix or make use of the backpack feature in Scratch, they sought help from Hunter's group. Last, students reflected on the ways that they sought information to solve their coding problems. They said:

Hannah: It, like, has Scratch tutorials and so we used those for, like, coding things.

Brayden: We made, like, a variable and like whenever you got a question right it would add, but then it just kept adding it and add like 1000 every time you did it. And so, like, we just, like, looked up how to do it and then we kind of focused on what it said and kind of copied.

Adam: This one time we were trying to borrow *Cough* (Steal) *Cough *Cough* a code from [our] teammate and I figured out how to do it [remixing] but my team didn't so I helped them by showing them how and we finally finished the game.

Brayden: Once me and my teammates had to solve a problem for the game to work properly because whatever answer you did, it said it was correct but then we looked at another project and copied it many times until it was finally correct and ready to be played.

The ability to seek answers to their own questions empowered students to grow their expertise in various aspects of coding a game in Scratch. Students made use of tutorials within Scratch and the ability to remix code from games available in the Scratch community. Each of these help students to grow their coding skills.

Building and testing code. Building and testing code helped students gain experience and confidence in their ability to create game elements. This is connected to problem-solving in the coding environment, which is discussed in another section. Building and testing code in this section refers to how students learned through their initial attempts at coding the elements for their games. Scratch provides instant result checking allowing students to see the results of their coding efforts and encourages trial and error learning (Ke, 2014). This helped build a culture of collaboration because students fell into natural patterns of co-coding where they helped each other build and test code. This was an important piece of growing student expertise. The ability to build code and immediately test it gave students instant feedback on their work. Video observations revealed times when students built and tested code and then right away wanted to show off their new skills to their team. This instant peer validation of their discoveries and work helped build student confidence in their skills and encouraged students to further learning. Students' reflections and focus group interviews revealed this connection to gained knowledge. My students said:

Shreya: We were working on coding the main sprite and we figured out how to use x and y to move our bat [sprite].

Brenna: I figured out how to make the character move.

Rachel: Our solution worked out because I eventually learned how to use the buttons and figured out a code if you get it right or wrong.

Brayden: I feel that I have improved in my coding skills this year.

This initial gaining of knowledge combined with the ability to test their coding solutions gave students immediate feedback on their performance as coders. Students who are confident in their abilities are more likely to share what they have learned by adding to the conversation (Khalili, 2004). Building and testing code in this way helped create a culture of collaboration as students often coded together and shared their discoveries.

Information sharing. Information sharing served two functions. It gave student experts the opportunity to share the knowledge about coding that they had gained, and it helped a new learner move toward expertise. For example, Kumari was the first student to use the text-to-speech blocks. After she showed her group how it worked, they soon spread across the class to share the knowledge with other groups. GT students need for their work to be valuable and valued (Diezmann & Watters, 1997; French et al., 2011). The development and sharing of information gave students the opportunity to practice their newfound expertise in an environment that valued their contributions. In their reflections, students wrote about the times they needed help with coding and the times they helped others. They wrote:

> Hunter: A time I helped a classmate was 2 times ago when Carter needed help getting music for his game. I chose this person because I knew how to use the backpack (thanks to Lacey) and saw he needed help with it, so I helped.
>
> Erin: Brenna's group also showed me and Rachel how to make a text box appear when they click the question, also how if you get it right, you move on.
>
> Cole**:** One time I needed help was when I didn't know how to make Scratch have questions you answer. Marcus. chose to help me.
>
> Mira: I asked for help from Shreya on coding because she knows lots about coding on scratch and because we needed to do something for the bat, and I was not sure what we are doing for some of the codes, so she explained to me. She also helped me create a sprite.
>
> Kumari: When I found out how to make them speak, I told my teammates and most of them got to make the characters on their level do that too.

These student reflections illustrate student's willingness to share information which eased the stigma associated with not having or not knowing an answer. Information sharing became an important portal for students to gain knowledge of coding. This also allowed for the emergence of student experts as the students shifted from seeing me as the expert in the room to seeking help from each other. This shared knowledge in turn allowed others to step up and pass on what they had learned from their peers.

Expertise grew through information seeking, building and testing code, and information sharing. These elements worked together in a manner that increased student knowledge of coding as well as creating new experts as knowledge was passed from student to student and group to group. The collaborative nature of this project and our classroom environment encouraged students to build and share knowledge.

Growing security in seeking help from peers. In developing a culture of collaboration, students not only saw themselves and their peers as novice experts (Salen, 2007), but they also became comfortable with seeking out solutions and advice from each other. A culture of collaboration affords students permission to ask for help. In game design-based learning students grow to understand and value each other's skills (Kim & Bastini, 2017). For example, about halfway through the study, we had a day where many of the students were absent. The students who were in class took the opportunity to share what they were working on. Students sat in small clusters and tested out each other's games. This day represented a definite movement forward as students excitedly asked each other, "How did you do that?" and "Can you help me do that?" Three concepts contributed to the development of this category, 1) peer-to-peer monitoring, 2) co-coding (collaborative coding), and 3) interplay of peer-to-peer monitoring and co-coding.

Peer-to-peer monitoring. Throughout the game design-based unit, students relied on one another to discuss criteria, identify goals, monitor progress, and share feedback (Herro et al., 2017). This checking in with one another revealed itself in both the video observations and student reflections. Peer-to-peer monitoring was coded 97 times in the videos and appeared in all ten videos. For example, one day as Grace and Eli were working on the hide and show sprite feature, Grace opened the tutorial section of Scratch to learn how the codes for hide and show work. Grace added the code to her program and shared the results with Eli. He excitedly responded, “We are amazing” gave Grace a high five. They then began discussing what to do next. Another example involved Adam, Gavin, and Lucas. Gavin was working on a flow chart for the game while Adam and Lucas were working on the game design document. These students checked in with each other frequently and stopped several times to refine their plan.

In addition to feedback around coding and game elements, students showed concerns for continuity of the various levels of their games and how they would eventually all fit together. This relates to peer-to-peer monitoring because students had to monitor the various pieces of their game to ensure their final product would fit together seamlessly. For example, at one-point Katie decided to change her sprites' skin tone. She checked in with each of her partners to make sure the character looked consistent throughout the game. In their reflections, students expressed concerns for continuity and the challenge of putting all of their work into one single game. They wrote:

Rishi: Like, if you work in teams, you're going to have, like, if you just start doing something random and the other person doesn't know it's not gonna, like, fit together correctly. I renamed the sprites with a number, so we knew which level it was in.

Brayden: He remixed mine and then he, like, added his, because we had the, like, exact same sprites so it was really easy to do it. It's way easier when you have, like, the exact same backgrounds throughout it

These quotes demonstrate how students displayed concerns for continuity in their games and how they monitored the progress of their games to ensure the parts would fit together. Peer-to-peer monitoring happened frequently throughout the unit and multiple times during a class session. Students relied on each other for feedback, direction, and to solve coding issues. This monitoring crossed over groups as students shared their learning and sought feedback from outside their project group thus strengthening our culture of collaboration.

Co-Coding. Collaborative coding occurred at times where students switched seats, traded laptops, or took control of either the keyboard or the mouse in order to help a peer with a coding issue. Co-coding involved some instances of troubleshooting which will be discussed in more detail in a later section. Ching and Kafai (2008) describe a range of collaborative interactions game design including clustered work where students intervene to fix coding issues. In our classroom culture where students sought and shared information and built and tested codes co-coding evolved naturally with shifting expertise. Co-coding looks at how students worked collaboratively in the coding environment. This was observed in nine of the ten videos and swapping of places, keyboards and mice was coded thirty-eight times. Frequently, the students were observed talking through the coding issue and the control of the keyboard or mouse would be switch back and forth as the problem was solved. For example, at one-point Madison was watching Katie work on some coding. When Katie finished, Madison ran the code and found a problem. The girls discussed what they thought the problem was, found the mistake and went to the coding to fix it. During this time, the two girls switched control of the keyboard and mouse as they talked through and solved the problem. Students also describe co-coding in their reflections. They wrote:

Katie: So, like we would kind of like switch and so we could still, like, see each other's [Chromebooks].

Tyler: One challenge I faced was that I couldn't find out the code to do what I wanted. I fixed this with collaboration with others helped me find what I was looking for.

Rishi: So, we kept showing each at our screen so we could, like, one level is not too much different from the other levels.

Students developed a pattern of co-coding where they worked together to create and code their games. This involved joint efforts to build and test code. Working together to resolve coding issues and move projects forward allowed students to gain security in seeking help from peers and strengthened our classroom culture of collaboration.

Interplay of peer-to-peer monitoring and co-coding. Peer-to-peer monitoring and co-coding worked together to lead to student security in seeking help from their peers. These activities provided a natural space for students to seek and share information. Figure 4.5 illustrates how peer-to-peer monitoring and co-coding worked together to provide a sense of security in seeking help. The small gears turning a larger gear will create more force. So, in the image peer-to-peer monitoring and co-coding work together to strengthen the impact of security in seeking help. In their written responses and in the focus group, students reflected on how they grew more secure in seeking help and advice from their peers. They said and wrote:

Amanda: If you did not know something, you could ask one of your team[m]ates for help and they will share what they have learned. I also changed in this area because I know I don't have to get so frustrated if I am confused about something, I can just ask a friend for a clue.

Hannah: You have to have, like, ask them, like, can you, like, help me?

Steven: Yes, I learned that it is ok to ask others questions and that sometimes, when something doesn't work, try to fix it and try again until it works.

Hailee: I needed help one time when I was stuck by trying to code my objects to go into the bins and I asked my table...Akash said yes so while I got help, Serenity was working on her slide, Akash helped me and I was able to code.

As evidenced by the above quotes from students, they saw this as a point of growth and change. Opportunities to monitor the progress of their games and the ability to practice co-coding led students to share and seek information from each other. Students became secure in knowing that they did not need to know everything. This security in seeking help from peers reveals the level of trust students developed with one another and added strength to our classroom culture of collaboration.

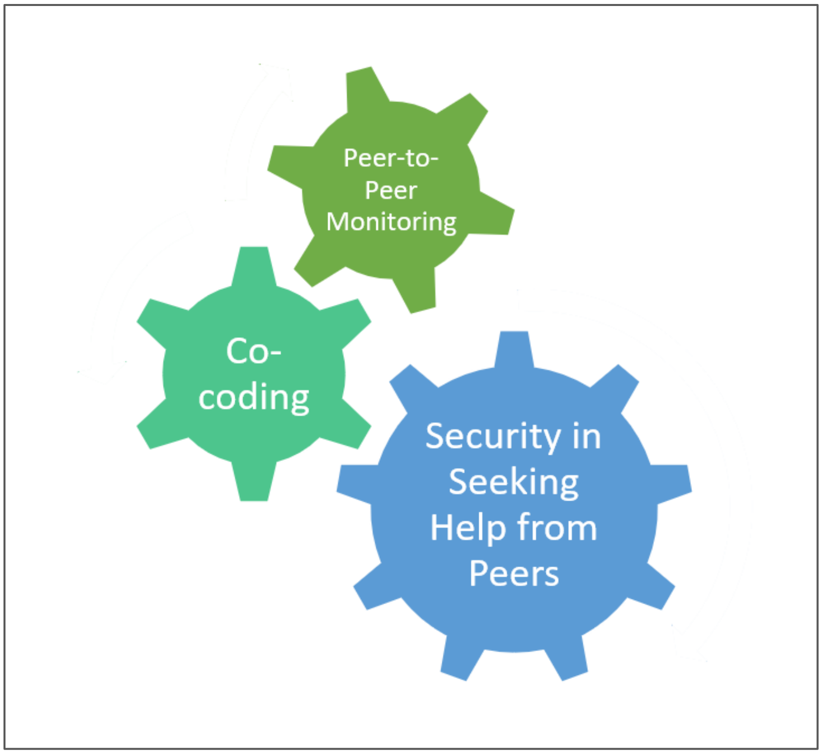

Figure 4.5. Illustration of the ways co-coding and peer-to-peer monitoring interacted with student security in seeking help from peers.

Summary of Theme Two. A culture of collaboration was developed through an emergence of student expertise and security in seeking help from peers. Emergence of student expertise included ways that students developed their knowledge of coding. This involved information seeking, information sharing, and opportunities to build and test code. Security in seeking help from peers evolved through collaborative coding and peer-to-peer monitoring of the project. Each of these elements worked together along with game design-based learning to create a classroom culture where collaboration was embraced as a part of the culture and seeking, sharing, and testing knowledge became the norm. Students expressed confidence in their knowledge and acceptance of not having to know everything.

Theme Three: Designing Games

Designing games to teach first-grade students about light and sound required my students to work together in order to develop a vision for their games that incorporated their team members' differing ideas. Disagreements on a wide range of design issues led to arguments that were sometimes emotional and posed difficult challenges for students. Creation of the game took sustained effort to continually work at incorporating shifting ideas about narrative and new coding skills. Incorporating content area concepts into games posed an added challenge for students (An, 2016; Ke, 2014). This theme looks at the creative challenges faced by students and how they included science concepts into their games. Two categories emerged a) crafting narrative elements, and b) incorporating science concepts into the games.

Crafting narrative elements. Crafting narrative includes consideration of storylines, characters, and setting. This emerged as flashpoint issues for students as they designed their games. Previous studies have found that the development of storyline or narrative is important in student game design (Akcaoglu, 2014; Burke et al., 2016; Kafai & Burke, 2014; Ke, 2014). In the current study, all students reported having some form of disagreement with their team during the design phase of the unit. While all students wrote about their teams' disagreements, nine students described it as *arguing* with their team. Eight students reported disagreements about developing setting and background, and 15 students reported disagreements about characters or sprites. Diego described these design disagreements as, "Our behavior changed from joking around and having some crazy ideas and joking about them to intense/heated reasons on why our way should be done and the advantages of them." Students used elements of narrative to establish personal connections with their work and add more personal meaning to their games (Bruckman & Resnick 1995; Baytak & Land, 2011; Kafai & Papert, 1996). This also challenged students to see other students' ideas as worth consideration as evidenced by the following student reflections:

Mira: We disagreed because we had good ideas.

Madison: I think we disagreed because we all thought our ideas were better than the other.

Hannah: My behavior changed when they did not agree with me by making me open to new ideas.

Many of these disagreements were resolved through incorporating multiple ideas into the storyline, adding levels, and using multiple characters to give each student a voice and ownership of the game that was being developed. For example, five students described this reconciliation process:

Katie: We decided at the end to put both ideas together to create one big idea that includes everyone's suggestions.

Sebastian: When we were deciding what our game format was, I wanted weapons to fight the bad guys but Lacy said no eventually we mixed our ideas and became a better time.

Madison: We compromised, and we did my idea for this one [level], Kevin's for another, and Katie's last.

Hunter: The information we used was a compromise to where the people I wanted to be good were evil and had powers.

Brenna: Both of the characters we chose were a different gender and you can only run as one at a time so, we came up with the idea for [a] choose your character [game].

Developing story elements provided students with a rich opportunity to explore and understand each other's point of view and to work together towards solutions that all students could agree on. These compromises helped students to expand their thinking and incorporate multiple ideas as well as to provide opportunities to create elements within the game that were personally meaningful to individual students. Narrative is an important element in many games. Story development is familiar to elementary students, therefore, integrating narrative elements represented and important entry into the process of designing games.

Incorporating science concepts into games. Incorporating science concepts into games was one of the goals of this game design-based learning unit. Ke (2014) found when students engaged in game design, their efforts were focused on developing the game world and story rather than integration of content. For my study, some students focused on story or game elements and added in science content later. While other students developed their narratives to include the science content. As game designers, my students approached integrating game elements such as narrative and game play with science content in the following ways: a) game world or story focus, b) quiz games, and c) games with integration of storyline and science. Case examples will be described for each type of inclusion of science concepts.

Gameworld or story focus. Three out of fifteen groups of students designed games that focused game mechanics, such as collecting items and avoiding harm or on telling a story. For each of these groups, science concepts were not present in their initial game design documents. Students were encouraged to go back to their design documents to add in science concepts. In reviewing their final games, science was not present or present in a very limited capacity. Table 4.9 shows game titles and student descriptions from their design documents.

Table 4.9. *Examples of Games with Storyline Focus*

Game Title	**Student Description of Storyline**
Bat and Centaur-	You have to pass through levels and collect items as you move because since you are vampires some things can harm you and will [take] lives.
Hogwarts Evolution	It is going to be in Hogwarts school of witchcraft and wizardry. You are not allowed to try to break out of Hogwarts or else something bad will happen. Also, in the forbidden forest. The sound is in jars that you have to collect but you CAN NOT let Voldemort take it.
Find the Light Bulb	Get through the control room while collecting objects for a lightbulb. Have to collect all the light bulbs. Don't get knocked out by the strong sound waves.

One team's experience depicts their emphasis on game narrative and mechanics. Claire and Addison based their game "Hogwarts Evolution" around the Harry Potter series (Rowling, 1997-2007). They were very focused on characters and setting. This passion for the storyline is evident in Addison's comments about their work on designing the game.

> A time when me and Claire came up with a creative or innovative design or solution to a problem was when Claire's level was about finding Dumbledore. I thought, why have a level about Dumbledore when he is just giving hints? So, on level two the character could ask Dumbledore if he could do anything and

> Dumbledore says go check on Snape. The character sees Snape with a spell on him to change into a girl and Voldemort as a dragonfly.

In describing times when they struggled, Addison shared the following:

> A time when I disagreed with my teammates was if Fawkes, Dumbledore's pet phoenix was going to be a character you could be. We disagreed because I wanted you to be able to fly around Hogwarts seeing every passage fast. But Claire did not want Fawkes to be in there. My behavior changed when they did not agree with me because it would be fun to fly around people enjoy that and they like to explore fast. So, I got mad because that would have been my favorite part of the game. Some information I used was it's a magical world and people want to have things you can't really do in real life in it. And the game should be fun and amazing.

For Claire and Addison there was a clear focus on narrative and game elements. Although they did include collecting sound jars, there was no science content included. The jars were just an item that the players were collecting to get to the next level.

Similarly, the other games in this category included storylines that involved collecting items, confronting a foe, and moving to different levels. These games included tangential connections to science content, for example sound jars or light bulb parts, or no science content at all. One purpose of the game design-based learning unit was to create games based on science content. It is evident that some students struggled with integrating science content with their narrative and game elements. These students' focus on narrative or game mechanics caused them to lose sight of the science content goal.

Quiz games. Five groups approached the challenge of incorporating science concepts into their games by taking a quiz approach. In these cases, the students developed some narrative elements such as character and setting but the storyline lacked a reason to be learning about or answering questions about light and sound. See Table 4.10. While these games met the goal of integrating science content, they presented a disconnect between the game action and the science content. In many cases, there was some action in the game that was interrupted by a science question. They used their characters and their actions to present the player with questions about either light or sound. There was a limited connection between the settings and actions and the science concepts being quizzed. This type of integration could leave a player confused about the purpose of the game.

Table 4.10. *Examples of Students' Quiz Games and Storylines*

Game Title	**Student Description of Storyline**
Light and Sound Football	Players must score a touchdown to win and you have to answer 3 questions per first down if you get 2 wrong on a set of downs you lose.
Light Run	Get to the other side of a prism and survive all dangerous obstacles and beams of light. If you get an answer wrong, you get hit by a beam of light and you lose a life. If you get it correct, you get to move forward safely.
Super Light World	You have to get to the other side and touch the light bulb and answer a question to complete the level. Also, you need to answer 5 questions total.
Glitter Pets	In this game you have to travel through exciting places with color pets. Throughout the journey you will have to answer questions.
The Adventurer	To go on a long and dangerous adventure to find the rainbow and get out and take out the mobs and bosses. And read the magic board to get past the levels and only survive with 3 health.

Two teams' games and experiences exemplify this characteristic. Brayden, Oliver, and Justin centered their game on their shared interest in football. The coding in their game involved moving characters forward on a football field. The movement was based on players' ability to answer questions about light or sound. See Figure 4.6. In the game there is no connection made between the football game and the questions about light and sound.

Figure 4.6. Screen shot from Light and Sound Football by Brayden, Oliver, and Justin.

Similarly, Isaac, Ryan and Carter wanted their game "Super Light World" to be like "Super Mario Brothers" with their character running through a scene avoiding obstacles and collecting lightbulbs. They were very focused on the action of the game and decided to use a quizzing format to incorporate the science content. Isaac described the process of adding light questions to their game "Super Light World" as follows.

> We decided to think of ways to implement light questions into our game. We came up [with] 2 ideas one was that you had to click on a light bulb in order to get to the next level. The other one was that if you died you had to answer a question about light.

In this category students used quizzing to incorporate science content into their games. Students used narrative elements such as characters and setting or gaming elements such as collecting items and avoiding obstacles. Their games were interrupted by questions about science concepts rather than blending in and fitting the storyline. Game elements create the game playing experience (Kapp, 2012) when there is a mismatch between elements as presented in this group of games, the experience can be disjointed and confusing to players.

Games with integration of storyline and science. The inclusion of science in the storyline showed up in student design documents for seven of the 15 groups. The games in this category successfully blended storyline and science content. See Table 4.11. Salen and Zimmerman (2004) describe narrative as important in games because it establishes temporary worlds and an invitation to play. The more complex the interplay of story elements and game elements, the more effective the game is (Kapp, 2012). Student games that incorporated science concepts into the storyline are described below.

Table 4.11. *Game Designs with Science Woven into the Narrative*

Game Title	**Student Description of Storyline**
Betty and Mr. Chicken	Betty and Mr. chicken are eating baked potatoes and tater tots Betty is confused as to why she can see through her glass cup and not her plate. Mr. chicken takes Betty around the house to teach her a lesson about translucent, transparent, and opaque objects.

Table 4.11. *Game Designs with Science Woven into the Narrative.* Continued

Game Title	**Student Description of Storyline**
Dungeon Escape	Someone has knocked you unconscious and you woke up in a dungeon. You look around and you see some locks on multiple speakers. There will be a sign that will tell you which one to click. For example: Walk to the speaker that has a high pitch and low volume. Click the speaker to hear the volume. You come across problems that you have to answer to collect the speakers.
Light Game	Kids have to find transparent, opaque, and translucent objects for the quiz. They need to know about the sun and find out more about the rainbow and how light works. The goal of the game is to help the kids pass the quiz, also called studying.
A walk by the Sea	In this game you will be identifying if objects are transparent, translucent, or opaque. You will answer your questions by typing in your answer, you will either be right or wrong. Translucent is when you can see a little light through the object, transparent is when you can see all the light through the object and opaque is when you can't see ANY light through the object.
Alexis and Alex's Science Sort	A girl named Alexis and her brother Alex needed help with their homework because they didn't know transparent, translucent, and opaque [and had to sort objects] into the bins and they need their 1st grade friend to do that.
Escape Room Maze	You're trapped in a room and have to use light to escape. Light up houses and pass through walls. Learn about attributes of light.
In the Jungle	There are people that have to find pieces of maps. At the end, you will have to put all the pieces together to level up. There will be signs that say stuff like, "High pitch is the next map piece." If you touch or find a siren, it will make a sound. If it is the correct sound, pick up the map piece

Two teams' games and experiences exemplify integration of narrative and science content. Gavin, Hannah, and Connor designed their game "Betty and Mr. Chicken" based around the idea that the character Betty does not understand why she can see light through some objects but not others. Their game design document included the following description: “Betty is confused as to why she can see through her glass cup and not her plate. Mr. chicken takes Betty around the house to teach her a lesson about translucent, transparent, and opaque objects.” See Figure 4.7. This group of students built the explanations of the light concepts into their storyline and then added levels so that players could practice. On the third level of their game there is a room where players match objects with their properties for example, a player would be asked to find all the opaque objects in a scene. Players earn points for identifying objects correctly.

Figure 4.7. Screenshot of Betty and Mr. Chicken by Hannah, Gavin, and Connor showing Mr. Chicken explaining opaque.

Another example of integration of storyline and science content was Dungeon Escape by Britanie, Grace, and Eli. In “Dungeon Escape,” players are given a clue about sound they should be seeking out. The players then have to test various speakers and identify the correct volume or pitch in order to be released to the next level and eventually escape the dungeon. Britanie explained how they integrated science with their storyline:

> The design element that we were working on was the speakers and what they would say if you got them right or wrong. We came up with the idea of the speakers was that we had to think of a way to involve sound and my team and I thought that sound comes out of speakers.

While the focus of the game design-based learning was to create games about sound and light, this group of students created games that were more complex and sophisticated than other games. They balanced the challenge of creating a game with creating a compelling narrative to fit their goals. Integrating storyline and purpose for the game was important to these groups of students as evidenced by their reflections. Students shared:

> Gavin: We wanted to make as real as possible so forgetting a notebook is something people do, and a city and school are very real places.
>
> Rachel: I came up with this idea because if she forgot she had a test it would be more fun to go get it from her house.

In each of these game environments, students incorporated both storyline and science content. In their introductions to their games, they set up the purpose for the playing and invited the player to help or participate. See Figure 4.8 and Figure 4.9. Thus, creating what Salen and Zimmerman (2004) refer to as the magic circle, an invitation to play, and a space or world in which the game is played. By integrating story line with content and the complex interplay game elements (Kapp, 2012), this group of students demonstrated a level of sophistication in designing their games.

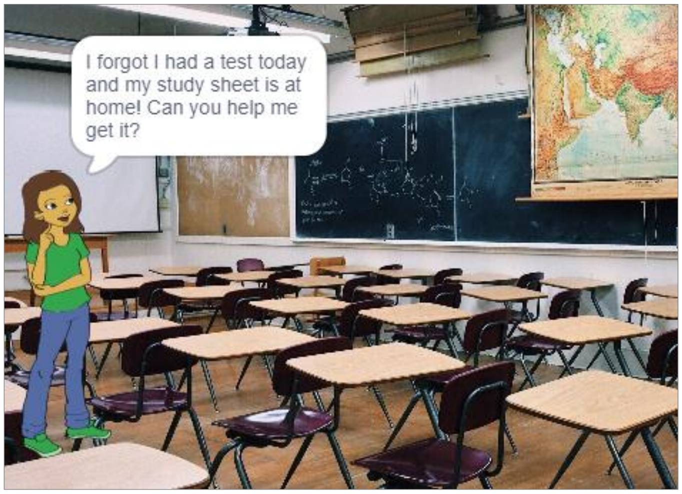

Figure 4.8. Screenshot from Light Game by Erin, Logan, Gabe, Rachel showing the sprite inviting the player to help with a study sheet.

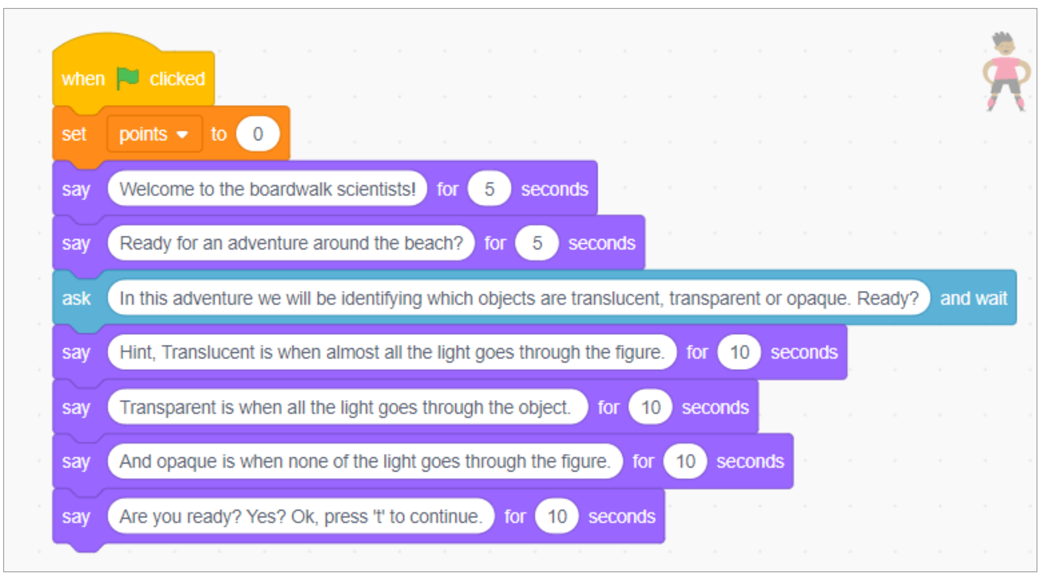

Figure 4.9. Screenshot from “A Walk by the Sea” by Cole, Lacey, and Marcus showing the coding for how players were invited into the game.

Summary of Theme Three. For all the groups, narrative elements presented an important entry point for creating their games. Students approached integrating science content into their games in different ways. Some students included the science content by creating stories and adding science concepts at a later point in development. Others approached the challenge by creating quiz games that had storylines that were separate from content. A third group created storylines that blended science with the other narrative elements. Each group used narrative elements to create their games at varying degrees of sophistication. Ke (2013) also found varying levels of content integration in student games. It is important to note the different approaches that students took in order to understand how they think about, or do not think about the integration of content in designing their games.

Theme Four: Problem-solving in the Coding Environment

The Scratch coding environment offered students many opportunities to problem-solve. For this study, problem-solving was defined as "tinkering with materials, testing boundaries, taking risks, iterating again and again" (Resnick, 2014, "Introduction," para 3) and troubleshooting (Akcaoglu, 2014). The other themes in this study are focused on collaboration and student reflection. This theme focuses on how students worked in the block coding environment, and specifically, how they built their coding skills and were able to solve problems. Several researchers found that teaching problem-solving skills in conjunction with programming and game design leads to higher levels of critical thinking (Akcaoglu, 2016; Cicchino, 2013; Su et al., 2014). The scope and size of the game design-based learning project provided multiple opportunities for students to problem-solve within Scratch. Through student reflections, observations, and focus group conversations, three categories of problem-solving developed: a) tinkering, b) pushing boundaries, and c) troubleshooting coding issues.

Tinkering. Tinkering within the Scratch environment involved students engaging with the elements in a playful way (Resnik, 2014), manipulating characters, backdrops, and coding. This is different from pushing boundaries and troubleshooting coding issues because it is an entry level activity in problem-solving, sometimes referred to as ‘‘low-floor” (Lye & Koh, 2014, p. 54) or easy for the students to pick up. In this study tinkering involved exploration and experimentation of the various elements in Scratch. These behaviors appeared early in the game design process while students were choosing, changing, and designing their characters, settings, and storylines and was consistent among most of the participants. Poce, Amenduni, and DeMedio (2019) found that tinkering built flexibility and improved creativity in critical problem-solving.   The following examples illustrate how students tinkered with their game elements.

In the focus group session, Katie reported:

> Madison was creative because there's this mixed button that you can, like, mix different colors...um, like, she would, like, make this girl have, like, roller blades that would have, like, colors on it, and... she would have, like, the hair different colors. It was really cool.

Like many students, Katie used a mix of colors to change her character’s clothing (see Figure 4.10). This allowed students to put personal touches into their games as a form of identity expression (Ke, 2014). Katie’s choice of colors reflects her preferences and personality.

While many students manipulated the coloring of sprites, Madison wove the element into the storyline of their game (see Figure 4.11). Within the game the player is trying to collect pieces of a map that will lead them to a treasure. Her character mentions a change of hair color and attributes it to something she touched in the previous level. By the end of this level she gets her hair color back when the player chooses the correct piece of the map.

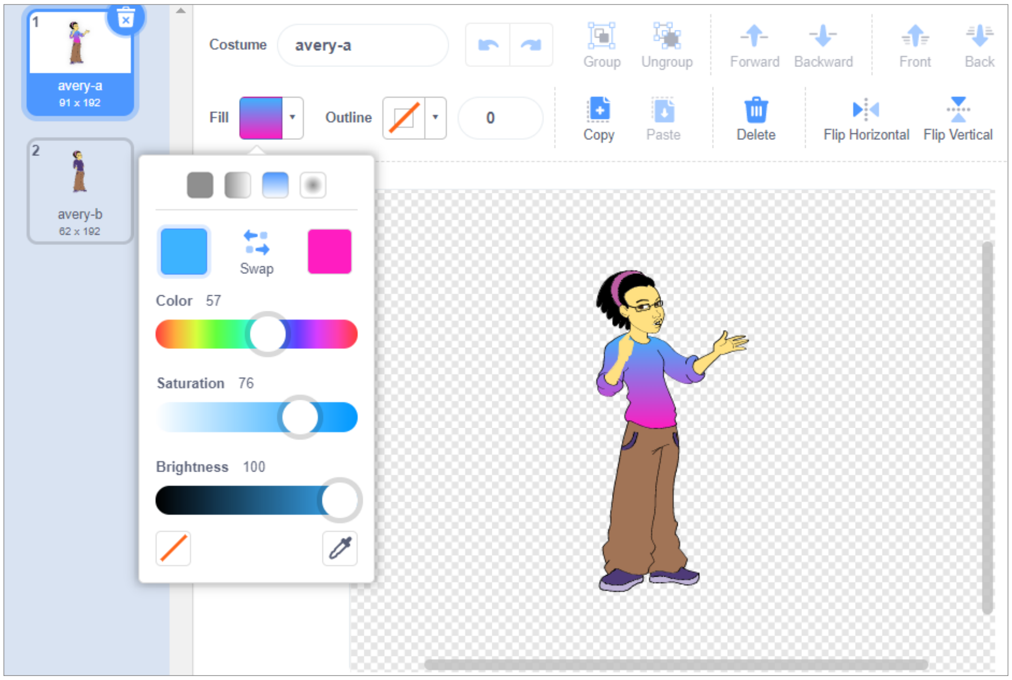

Figure 4.10. Screenshot from Katie's game showing the mix color function in Scratch.

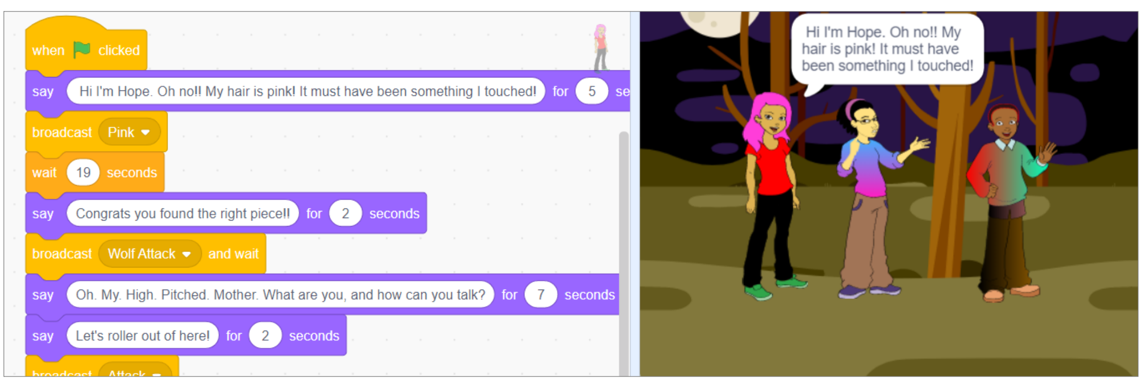

Figure 4.11. Screenshot from Madison's game showing a character's change of hair color woven into the storyline.

Kumari provided another example of her team's tinkering with color options (see Figure 4.12):

We were working on designing our game and we came up with the idea that we should change the colors of the clothes so they could look like different people. We came up with the idea because we wanted to use a lot of colors since the game was called Color Pets. It was a team effort because everyone in our group made at least one change to the colors in their level. It worked out because we had a lot of different colors, and we had characters that looked like they were in different clothes. So, that was cool and creative.

Figure 4.12. Screenshots from Glitter Pets by Kumari, Tyler, Khloe, and Ankita showing change of color in character clothing.

Rishi and Cal added lines to their chosen backdrops to create a maze (see Figure 4.13). In the focus group discussion, Rishi reported:

Most of it was like an escape room. Like, you have to get through a maze basically, and then you have to choose between the three walls, which would be mixed up every time or sometimes there's more walls. Like, some are opaque, some, like, which are black, some are translucent, and which are white, and then some are transparent, which are like clear.

Figure 4.13. Screenshot from Rishi and Cal's game showing the maze lines that they added to their backdrops.

The sound options in Scratch offered another opportunity for students to tinker and play. Many students spent time recording and manipulating sounds. (see Figure 4.14). During the focus group discussion, Brayden reported:

> We also had someone [Hunter] in our group who like they would get the sound from the Scratch thing and they, they'd click on it, they'd like speed it up and they'd be like, oh look at this, look at this. And they go around like showing everybody like look at this thing I made.

Figure 4.14. Screenshot from Hunter's game showing both recordings he made and sounds from the Scratch library.

This early tinkering with sprites, backdrops, and sounds gave students an opportunity to play inside the Scratch environment. It was an entry point for problem-solving where students explored what was possible in the Scratch environment. The problems that students were solving were the basic how-to problems in Scratch, i.e., how to personalize a sprite, how to change a background, and how can sounds be manipulated and changed. This exploration and experimentation allowed students to put their own touches into their games and practice problem solving collaboratively in the coding environment.

Pushing boundaries. Pushing boundaries involves students exploring ideas and considering new possibilities (Resnick & Rusk, 1996). Unlike tinkering, pushing boundaries involves coding or designing on a higher level. This category directly relates to problem-solving because students had to grow beyond basic coding to create elements in the game that matched their vision. As Rachel stated,

> I knew I would never finish in time. So, I had to use my creativity to think of ways the game could be better and [the coding] would take less time. I had to problem-solve all the coding [in] it [the game] to do these big ideas.

Rachel's statement illustrates the grand ideas that students had to balance out with both their limitations in coding and time constraints. The problems students encountered represented a gap between what they knew and what they wanted to know. According to Jonassen et al., (2003) "design is the most complex and ill-structured kind of problem solving" (p. 138). In pushing boundaries, students engaged in more complex coding using if-then statements, applying variables to keep score, and using coding blocks that need to be added from the extensions section of Scratch. Seven of the fifteen groups reached this level of pushing boundaries. Examples of pushing boundaries included adding text to speech blocks; adding hidden elements or Easter eggs to the program; and using if-then blocks, variables, and lives as part of programming. Each of these is discussed below.

Towards the end of the unit, as we were preparing for the first-grade students to come in to try out the games, Kumari decided to have her younger sister try the game at home. She shared with her group and then the whole class that the words were going by too fast for her sister to read. She went in search of a solution and found the text to speech function (see Figure 4.15). In her end of unit reflection Kumari stated:

> When I found out how to make them speak, I told my teammates, and most of them got to make the characters on their level do that too. So, collaboration helped me share my ideas with my teammates and we ended up with a really good game.

Figure 4.15. Screenshot from Kumari's game showing the codes added to make the sprite both speak and produce a speech bubble.

Another example of pushing boundaries was when Adam, Gavin, and Jackson decided to put a hidden element, referred to in games as an Easter egg, into their game (See Figure 4.16). Jackson shared:

We were working on the first level. We came up with the idea that we should make little sprites that we hid in the levels. There was one per level and if you clicked it, it would make a sound. We worked together to pick what sprite and where to put it; we also picked the sound. After we were done it worked pretty well. We're thinking about putting something at the end if you get them all.

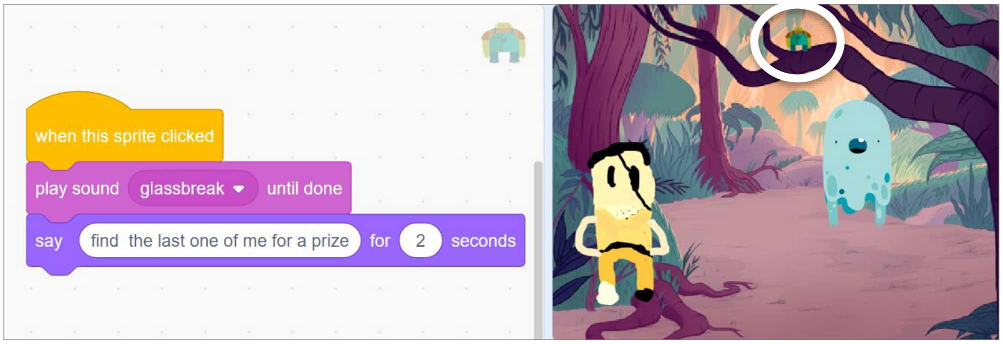

Figure 4.16. Screenshot of game by Adam, Jackson, and Gavin showing the sprite hidden in the tree.

Four groups used the if-then-else block and variables within their game for scoring (See Figure 4.17). This did lead to many troubleshooting issues that will be discussed in the following section. One group used hearts to represent lives, a common game element in (see Figure 4.18). Each time a player got a question wrong, they lost a life. Through several iterations of working with the if-then coding, the students came up with a simpler solution using the hide and show blocks to create this element of their game.

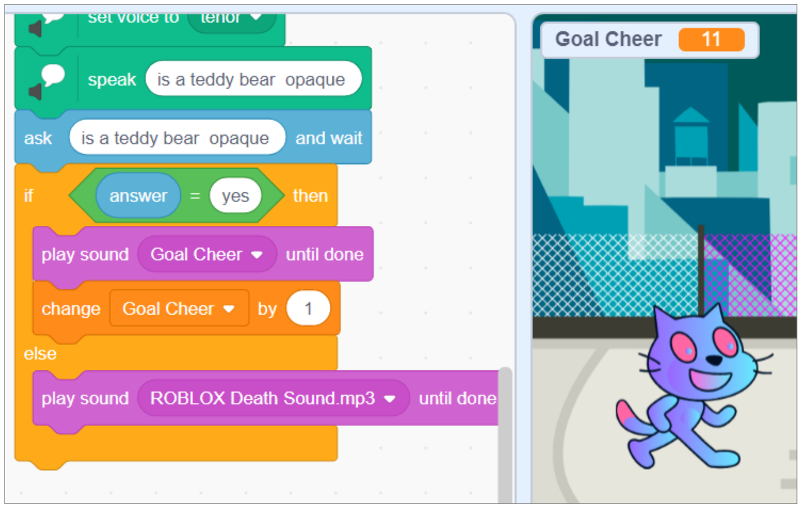

Figure 4.17. Screenshot from Tyler, Ankita, Kumari, and Khloe's game showing the use of if-then-else block and scoring using the variable "Goal Cheer".

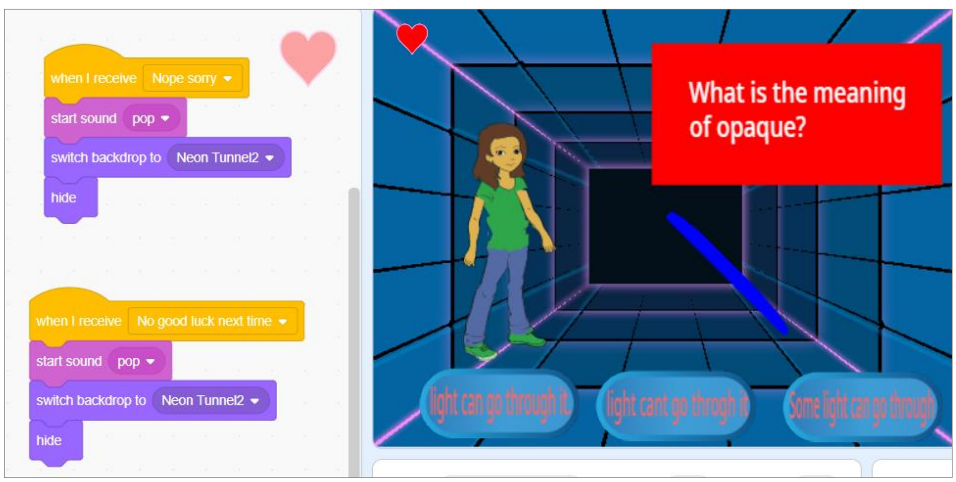

Figure 4.18. Screenshot from Ayden, Brenna, Jacob, and Steven's game showing the use of hide and show to power up and down the character's lives.

While each of the elements discussed above — adding text to speech blocks, hiding Easter eggs, and using if-then-else blocks — are not new concepts in the gaming world, for these students, it was an opportunity to try something new and novel. Many of their previous coding experiences had been in scripted lessons where all the students created similar projects. Britanie reflected, "If we use directions for a game, it won't help us in life because we don't get a handbook for life.” game design-based learning gave students some freedom to explore what was possible within the Scratch coding environment. They were able to push boundaries in a way that is not present in scripted lessons. These examples illustrate the concept that when students faced authentic problems, they searched for solutions and pushed their own boundaries of what they originally thought was possible.

Troubleshooting coding issues. Troubleshooting involves finding the faulty part or the element within the system that is causing the malfunction (Akcaoglu, 2013; Akcaoglu & Koehler, 2014) and correcting it. This means analyzing and identifying the cause of an issue or problem. Troubleshooting opportunities can arise during both tinkering and pushing boundaries. Although tinkering and pushing boundaries can occur without the need to troubleshoot, as mentioned earlier, using the coding blocks for variables posed many challenges to the students. Troubleshooting assumes that the code is not working and needs to be fixed, and represents problem-solving at a higher level, unraveling code and solving technical issues (Brien, Friedman-nimz, Lacey, & Denson, 2005). Akcaoglu (2014, 2016) and Akcaoglu and Koehler (2014) found significant gains in troubleshooting through game design-based learning. As part of the focus group discussion, Brayden shared the issues that his team had with using a variable to keep score within their game. He said, “We made, like, a variable and, like, whenever you got a question right, it would add, but then it just kept adding it and add, like, 1000 every time you did it.” Hannah shared that her group also had trouble with using variables. She stated, “We had to, like, figure out how to, like, stop it [from] keep adding points every single time. “Cause when I started [we had] 57 points; we didn't know how to stop it." Hannah and Brayden both stated that they knew about the block but had to try a few times to figure out where to place the block in their game so that it worked properly. Rishi knew how to fix this, and the students had an extended conversation about using the reset variable block to fix the problem. This issue also came up in several final reflections written by the students toward the end of the unit:

> Rachel: Our solution worked out because I eventually learned how to use the buttons and figured out a code if you get it right or wrong.
>
> Tyler: One challenge I faced was [that] I couldn't find out the code to do what I wanted. I fixed this with collaboration with others [who] helped me find what I was looking for.
>
> Brayden: Once me and my teammates had to solve a problem for the game to work properly because whatever answer you did, it said it was correct…. We came up with the idea when Justin asked me what happened when you got a question wrong, and the answer was just saying, "good job!" This problem and solution was a team effort because we both had to figure out how you actually did it.

Another instance of troubleshooting code came up with Eli who was working with an if-then block (see Figure 4.19). He described his growth in problem-solving in his final written reflection as follows:

> I felt really good when I solved the "glitch" in Scratch. I have definitely grown throughout this project. When my mom showed [me] Scratch 2 years ago, I had absolutely no idea what it was. Now because of you I can make entire projects. (You might want to check them out), [student use of parenthesis].

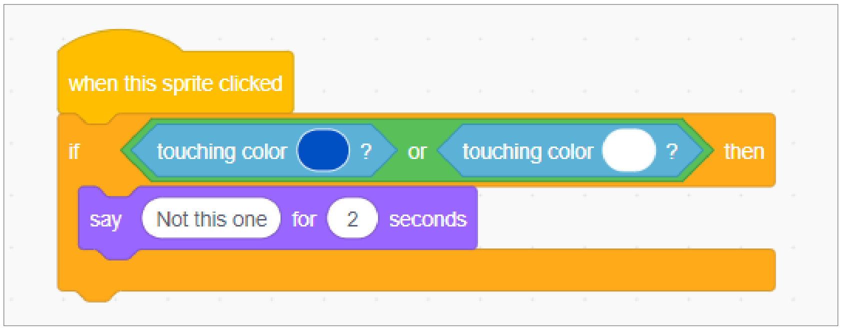

Figure 4.19. Clip of the code that Eli was struggling to make work correctly.

Troubleshooting required students to have a certain level of coding knowledge and an understanding of how the system worked (Jonassen et al., 2003). As each team came across coding that did not work as expected they had to troubleshoot their work in a systematic way. For my participants, this meant analyzing how each part affected the whole program. This type of problem-solving relied on gained knowledge and experience with the coding system. In finding, analyzing, and fixing coding, students were able to engage in critical thinking to solve problems in their games.

Summary of Theme Four. As students progressed through game design-based learning, they encountered multiple opportunities to solve problems that arose. In the beginning, tinkering allowed students to play within the program by testing possibilities and personalizing characters, backdrops, and stories using color and sound tools. The problems students were solving were preferential in nature and had to do with the aesthetics of the game. Next, pushing boundaries engaged students in using code and game design elements to enhance their games. Students added Easter eggs, text-to-speech blocks, and used if-then coding to their games. This type of problem-solving allowed students to use what they had learned to add actions and elements to their games that made them more like the games they play online. Finally, troubleshooting focused students' attention on analyzing and fixing problems within their own coding. Students had to use their knowledge and experiences to fix coding errors in their games.

Theme Five: Reflecting on Learning

Reflecting on learning is an important element of project-based learning (Grant & Branch, 2005; Harel & Papert, 1991; Kafai & Resnick, 1996). This practice gave students an opportunity to think about the work they have done, embrace their successes, and understand the limitations of their game designs. For my students this meant opportunities to value the work they accomplished and recognize their own growth as learners. Reflecting on learning ties to the other themes, because as my students worked through the process of game design-based learning, they were constantly evaluating their progress and identifying needs for improvement in their games. They were also reflecting on their growth as learners and their roles within our learning community. Reflecting on learning included student statements about 1) coping with project constraints, 2) defining and enacting creativity, 3) growing self-efficacy in collaboration, and 4) expressing pride in the work that was completed.

Coping with project constraints. Project constraints are a normal part of real-world working conditions (Jonassen, 2011). Working within constraints is challenging for GT students who often have difficulty balancing between the originality of their thinking and the usefulness of their product (Beghetto & Karwowski, 2107). This ties to the theme of reflecting on learning because it provided students an opportunity to think about limitations in a way that did not lead to giving up on themselves or the project. The challenges students encountered varied depending on their vision for the game. For example, Addison shared the conflict between her partner's vision for the game and their abilities to achieve that vision:

> Me and Claire got in a fight because she wanted me to make the real Voldemort and Snape, but I could not even do Harry Potter, so I said, "No." She tried it, but I told her the way Scratch works and its characters. It will not turn out how you expect it.

In addition to skill and program constraints, many students faced time constraints as the semester came to an end and they had to make adjustments to their game design plans. The complexity of designing and developing a game takes considerable time to complete (Khalili, 2014; Robertson & Howells, 2008). Ultimately, most groups were successful in completing the game, as they worked around both time and skill limitations. For example:

> Adam: One time, my team and I were going to make our character Robert shoot bad guys, but we decided that was way too complicated, and we were struggling to find a solution, so Jackson decided to do a trivia idea instead…. The trivia worked like a charm, and now our game is almost done.
>
> Rishi: We were going to mash it up; then we realized we had no more time, ... but we still had a bit of, like, maybe like 10 minutes left, so we wanted to use that.
>
> Grace: One of the things our team disagreed about was how many floors there should be. We disagreed about that because of how much time we had left to do this project and of how little we got done.

Britanie: When we were deciding, we had to think about how much time we had and how many ideas we had for each floor.

Katie: Um, we couldn't figure out how to connect our levels, and we didn't have the time to, so, when the people [first grade students] came in we, like, kind of work[ed] together to find a plan, 'cause we finished most of the levels; like, we finished most everything and all the levels.

Sebastian: We were not so skilled enough to do that repeatedly because it would take too much time but, we gave the bat the stuff it would need to survive at the beginning.

As shown above, many students did not connect their levels before their meeting with the first-grade students. Coping with project constraints gave my students an opportunity to reflect and make choices about how to spend their time in developing their games. This also impacted their design decisions as they worked to manage both time and expectations.

Defining and enacting creativity. Defining and enacting creativity included the ways students explained what it meant to be creative in the design process. Kaufman and Beghetto (2009) define this type of creativity as mini-c and it represents "novel and personally meaningful interpretation of experiences, actions, and events" (p.3). My students expressed their own judgements on what creativity was. For example, students used the phrases *out of the box*, *something you've never done before*, *new way of doing something*, and *new ideas* to define their creativity. Defining creativity led my students toward ownership of their creativity and their creative actions. Students shared:

Brayden: [It's] like a solution to a problem... you gotta be creative to come up with a good answer, because if you're not, then ... it probably wouldn't work.

Erin: I worked harder on a skill, creativity. My brain had to think.

Rachel: So, I had to use my creativity to think of ways the game could be better and would take less time…. My creativity has gone from "What the heck are we going to do?" To "I have so many ideas to choose from."

Hannah: Anyways, we made, like, random creative names, and the person [sprite], she was learning about lessons on light and, like, translucent and transparent and opaque things, was [named] Mr. Chicken who was a duck (laughing), and that was, like, just really fun to be creative and do fun stuff with it.

Mira: I feel like I improved most in creativity because I changed my usual just hearts and rainbows to spooky, like, monsters.

The game design-based unit gave my students an opportunity to explore their creativity and embrace their creative actions. For my students, creativity meant generating new ideas, adding on to other's ideas, showing an openness to new experiences, and putting things together in unique ways. In their final reflection prompt, over half of the students chose to write about their growth in the area of creativity.

Developing self-efficacy in collaboration. Developing self-efficacy in collaboration meant that my students came to believe in their abilities to work together in teams in productive and effective ways (Kafai & Burke, 2014). As discussed previously, students were not initially enthusiastic about having to work in teams. This is different from the theme of overcoming the challenges of group work in that it focuses on reflections of individual growth. This was a significant development for many students. For example, Diego shared, "I feel I have grown in my abilities. I used to not work well with others, but now I have improved in that area." This category explores how students changed and their reflections on their growth in collaboration. Students wrote:

Kumari:	So, collaboration helped me share my ideas with my teammates, and we ended up with a really good game.
Cole:	I have grown in collaboration, and I know this because in the beginning of the year, I preferred no partners, but now I do.
Steven:	In collaboration with my group, we agreed on ideas and listened to others. I have changed by working better with team members.
Ankita:	Another thing I am good with is collaboration, because when we were coding, we did not fight about who did what; we just did, like, that [the coding].
Marcus:	At one point we had no idea how to create questions, but we found out how to do it, worked together and collaborated, and got it done.
Gabe:	I feel like I have grown with my collaboration skills. I now feel like I can be stronger with my social skills and that helped us get the job done.

Students' development of self-efficacy in collaboration helped them recognize a change in themselves and their ability to work collaboratively with others. Through this game design-based learning experience, students were cognizant of their own contributions to their team's efforts. Students also highlighted significant collaboration skills such as listening to each other, agreeing on ideas, and sharing ideas. These skills helped students to grow in their beliefs that they could make significant contributions to the work of their teams.

Expressing pride in the work that was completed. Participants' pride in their work was illustrated through statements about their growth and their accomplishments. Salen (2007) reported expressions of pride among middle school game designers. The code, *expressing pride,* was present in three of the four student reflection responses, and it came up in the focus group interview. Students were able to reflect on the work that they had done well and identify ways they had grown from the project. The combination of a challenging task and recognition of achievement leads to increased motivation (Housand & Housand, 2012). Robertson and Howells (2008) found that ownership of learning and self-determination within game design-based learning were "powerful levers for learning" (p. 575). Expressions of pride included instances of overcoming coding challenges and generation of ideas. Students shared:

Ankita: A thing that I am proud of is coding 'cause I'm worried about coding, but I did, like, one level, and I was really proud of it.

Jacob: We had two amazing ideas that everybody agreed on, so then we all decided to go with the most creative one, and it is working out perfectly because it is creative and helps kids learn.

Katie: Surprisingly, we had about, like, five backgrounds, and they all had different transitions, and it just went all smoothly.

Eli: I felt really good when I solved the “glitch” in Scratch.

Brenna: Our solution worked out great because now the game seems more fun and professional.

Expressions of pride and satisfaction in work that is well done are important elements in reflecting on learning. For my students, these reflections afforded them the opportunity to celebrate their successes and evaluate their own growth as learners. This was particularly striking because although students received feedback from me, the work they did in STEAM class was not graded. Students put in significant time and effort to complete the games. Their rewards were intrinsic, rather than grade driven. For GT students, intrinsic motivation has been linked to autonomy over project, challenge, and cooperation (Housand & Housand, 2012). Game design-based learning provided a balance of autonomy, challenge, and cooperation for my students.

Summary of Theme Five. Game design-based learning gave my students opportunities to reflect on their learning. First, students were able to recognize and deal with project constraints such as time and skill levels. Second, they were able to define and enact their own sense of creativity. The games they built represented personally meaningful artifacts for their learning. Next, student development of self-efficacy in collaboration was evident in many of their statements and presented a shift in thinking for this group of students. Finally, they experienced intrinsic motivation for their learning and expressed pride in the work they had done.

Chapter Summary

For this study, both quantitative and qualitative data were collected. Quantitative sources included 1) Creative Self-Efficacy Survey, 2) Collaboration Survey, and 3)

Sound and Light Science Test. The findings of this study indicate that students' perceptions of their abilities in creativity were already positive and involving GT students in game design-based learning in science had a little impact on student perceptions across the two parts of the measure. Students' perceptions of collaboration, however, increased after the innovation and were statistically significant. Student content knowledge of light and sound concepts also increased from this innovation and were also statistically significant.

Qualitative sources included student reflections, game design documents, videos, a focus group, and student games. Five themes emerged from the data including 1) overcoming challenges of group work, 2) developing a culture of collaboration, 3) creating narrative and connecting science, 4) problem-solving is Scratch's coding environment, and 5) reflecting on learning.

"Overcoming the challenges of group work" was particularly important to my GT students who overwhelmingly reported they preferred to work alone. Game design-based learning provided students with a complex task requiring collaboration in order to complete (Winstanley, 2010). Another important element was equitable distribution of work. Within teams, students had to learn to manage project plans and maintain communication, which involved monitoring their task through questioning, information sharing, feedback (Herro et al., 2017).

"Developing a culture of collaboration" in the classroom meant having students take a leading role in their learning. As students encountered coding issues, they sought their own solutions and shared knowledge. Emergence of student expertise led to an environment where students felt comfortable in seeking knowledge from each other. One student wrote: “Now I don’t have to get so frustrated if I am confused on something, I can just ask a friend for a clue.” Sharing within and across groups became the norm.

“Designing games” required students to work together in order to develop a vision for their games that incorporated their differing ideas. Creation of the game took sustained effort to continually work at incorporating shifting ideas about narrative and new coding skills. Crafting narrative and incorporating science concepts were the categories for this theme. Some students got caught up in developing the narrative gameplay and either left out the science or only included it tangentially. Other students approached incorporating science concepts through developing quiz games where the game was interrupted by seemingly random questions about light and sound. A third group was successful at integrating their storyline with the science content. These students produced more sophisticated and engaging games.

“Problem-solving in Scratch’s coding environment” offered students opportunities to problem-solve. Researchers found teaching problem-solving skills in conjunction with programming and game design led to higher levels of critical thinking (Akcaoglu, 2016; Cicchino, 2013). For my students, this included tinkering within the Scratch environment, playing with color and personalizing characters. As students pushed boundaries, they used coding and game design elements to enhance their games. Finally, troubleshooting provided opportunities to practice analyzing and fixing coding errors.

“Reflecting on learning” is an important element of project-based learning (Grant & Branch, 2005; Kafai & Resnick, 1996). This practice gave my students an opportunity to think about their work, embrace their successes, and understand the limitations of their designs. For my students, this meant coping with project constraints, including time and skill levels. This also represented an opportunity for students to define and enact creativity and express pride in the work that they had done. Reflection provided the space to value work they accomplished and recognize their growth as learners.

CHAPTER 5

DISCUSSION, IMPLICATIONS, AND LIMITATIONS

The purpose of this action research was to describe the impact of digital game building on fourth grade GT students' growth in problem-solving, creativity, collaboration, and science content knowledge at Cori Elementary School. Quantitative (i.e., creativity and collaboration presurvey and postsurvey, and light and sound pretest-posttests) and qualitative data (i.e., student reflections, game design documents, focus group interview, video recordings and student final games) were collected and used for data analysis. Five themes emerged from the qualitative data analysis (see Table 4.8). Through the game design-based learning innovation, students experienced overcoming the challenges of group work, developing a culture of collaboration, creating narrative and connecting science in game design, problem-solving in the coding environment, and reflection on learning. This chapter includes a) discussion, b) implications, and c) limitations of this research.

Discussion

The literature on gifted learners, problem-solving, project-based learning, and game design-based learning help to situate this study into the larger body of knowledge. To answer the research questions, both quantitative and qualitative data were combined to capture a more holistic picture of the impact of game design-based learning for fourth grade GT students. The discussion is organized by the four research questions covering a) problem-solving, b) creativity, c) collaboration, and d) science knowledge

Research Question 1: What kinds of problem-solving interactions occur during a game design-based learning science unit for fourth grade GT students at Cori Elementary School?

Game design-based learning can provide student opportunities to solve both structured and ill-structured problems (Akcaoglu, 2014; Ruggiero & Green, 2017). Structured problems have one answer and are based on processes (Jonassen, 2000; Ruggiero & Green, 2017). Ill-structured problems are those that do not have one solution and cannot be reached by following a process (Jonassen, 2000; Ruggiero & Green, 2017). Validity of everyday problems vs big problems equally important to student development.

Jonassen et al. (2003) categorized eleven types of problems for learning. Three of the types of problems are most appropriate to this study because they matched my students' problem-solving experiences in game design-based learning. The research findings suggest that students' problem-solving interactions revolved around a) decision-making problems, b) design problems, and c) troubleshooting problems.

Decision-making problems. Decision-making problems are the typical problems we face every day and involve weighing options and making choices (Jonassen, 2000). Game design-based learning provided my students the opportunity to work together to make a wide range of decisions. In game design, students need to plan and create complex narratives, including characters, and settings, in addition to creating game elements including rules and interactions (Akcaoglu, 2014; Ruggiero & Green, 2017; Yang & Chang, 2013). Ke (2014) found that participants spent the majority of their time on negotiating and designing their game world and used this as an opportunity to project their identities into the game. In the beginning of this study when students were making decisions about characters, setting and storyline, they had to work together to make team decisions. This involved negotiation, compromise, and reaching consensus. For example, Hunter shared: "We used a compromise to where the [character] I wanted to be good was evil and had powers. The [character] that my teammates wanted was good but with no powers." and Khloe wrote about coming up with a title for their game: "We decided to take both ideas and turn them into one name." When students could not come to an agreement, they reported using "rock-paper-scissors" and "popular sovereignty" as fair ways to decide how to move forward.

This confirms Akcaoglu (2014) findings that students made gains in solving decision-making problems. Within game design-based learning, students must make choices based on game constraints and when choosing narratives students need to consider storylines that best represent their ideas.

Design problems. Design problems are ill-structured and complex with infinite possible solutions, solving design problems requires balancing needs and constraints (Jonassen et al., 2003). Within game design, students need to analyze interactions within the structure of a game to ensure that a game has a balance of challenge and success (Kim & Bastini, 2017; Prater, 2016).

"Tinkering and pushing boundaries" from Theme Four illustrate how my students approached design problems in their games. Through tinkering, students were able to discover some of the possibilities within the Scratch coding environment. For example, students were able to remix and create backgrounds and characters for their games. As students made these discoveries, they began to alter their storylines to incorporate new events. For example, Madison started playing with her character's hair color. Her group ended up incorporating this into their story. This attention to their storyline illustrates that while the students were attempting to place some fun and surprising elements into their game. They were also balancing the need for the game to make sense to their audience.

In pushing boundaries, one group considered audience engagement through hiding an Easter egg (a common gaming mechanism) in each of their scenes and challenging their users to find each one. Another example comes from Kumari who tested her game out on her little sister. Kumari soon realized that her sister could not read as fast as the text was being presented on the screen. That night she searched out a coding solution within Scratch. She came back the next day to share the text-to-speech code blocks with the rest of the class. This type of design consideration illustrates how students balanced their vision with the needs of their audience.

This study confirms Ke’s (2014) finding that student design thinking revolved around the game world or story crafting. Students approached the task of game design with varying visions based on their game preferences and their story preferences. For many of my students, considering constraints of the project were balanced with their needs, the needs of their group, and the needs of their end users.

Troubleshooting and diagnosis problems. Troubleshooting is problem solving through diagnosing and fixing faults in a system (Jonassen, 2000). Troubleshooting coding issues involves analyzing code in order to solve technical issues (Brien et al., 2005). Students in this study faced many coding challenges in dealing with if-then statements and variables for scoring. For example, Brayden, Hannah, and Aiden all reported having issues with scoring in their games. Discovering solutions forced students to analyze the systems they built (Akcaoglu, 2014), find the point where the code was not working as expected and fix the code. For my students, this posed some of the most challenging work that they did. Brayden shared: "So, you like, check every single thing and it takes forever to actually finally get it right." Another example arose during the focus group when students were talking about using variables for scoring. Rishi shared: You didn't put that block [to] set it back at zero when the game starts again."

This study confirms Akcaoglu, (2014, 2016) and Akcaoglu and Koehler's (2014) findings that significant gains in problem-solving have been found in game design-based learning as students are called upon to evaluate and remediate coding errors An (2016) also found that in troubleshooting, students were problem-solving at a higher level as they unraveled code and solved technical issues.

Research Question 2: In what ways will a game design-based learning unit impact fourth grade GT students' perception of their ability to be creative and innovative in science at Cori Elementary School?

To answer this question both quantitative and qualitative data were collected. The quantitative source was a survey that included items about general creative self-efficacy and specific questions about creative self-efficacy in science. Paired sample *t*-test results for student pre- and postsurvey scores for creative self-efficacy in science (M = 19.56 v. M = 19.36) and creative self-efficacy (M = 38.44 v. M = 39.25) showed no significant difference. It should be noted that student presurvey scores were high. For creative self-efficacy in science, all means were above 3.5, and for creative self-efficacy the means were all above 3.33 on a 5-point Likert scale. This indicates above average levels of creative self-efficacy in general and creative self-efficacy in science for this group of students. Although survey scores did not show significant difference as measured by *p* values, student responses to specific survey items, reflection questions, and focus group interviews did demonstrate the magnitude of the experience for my students.

In reviewing the literature about creativity, the impact of the environment was noted by several authors (Amabile, 2013; Kaufman & Beghetto, 2009; Torrance, 1972). This brought to mind the culture of collaboration (Theme Two) that was built in my classroom and illuminates the importance of nurturing creativity. Generating ideas and crafting narrative both emerged as important elements in my data. Students' reflections showed strong connections to their ideas and how they crafted the narrative of their games. The task of building a game to teach younger students about the science of light and sound provided my students the opportunity to express their creativity through 1) nurturing creativity, 2) generating ideas, and 3) crafting narrative.

Nurturing creativity. Creative self-efficacy is tied to intellectual risk taking in science emphasizing the need to create positive learning environments (Beghetto, 2009). Amabile (2013) points to the necessity of developing domain relevant skills and the positive impact on environment in nurturing creativity. Several authors (Amabile, 2013; Beghetto & Kaufman, 2007; Runco, 2014) describe a continuum of creative potential and performance that range from everyday acts of creativity to significant acts of creativity. Kim (2019) identifies four elements that must be present to nurture creativity including: having high expectations, challenge, interactivity, and space for deep and free thinking. Navarette (2013) found that in game design the more experienced at coding students were, the more creative students felt. Navarette posits that there are three levels of creativity that are tied to student levels of experience in coding and design: (a) entry level descriptions, (b) describing students' uses of imagination, and (c) emotional elements tied to the creative action.

Navarette (2013) reported entry level descriptions of the creative process in game design as interacting with colors and drawing, which closely aligns with tinkering (Resnick, 2014) in Theme Four. For my students, this meant manipulating sprites and backgrounds by adding their own colors or elements. For example, my students reflected on their creativity in terms of changing "the colors of the clothes so they could look different," (Kumari) and giving "this[sprite]...roller blades that would have, like, colors" (Katie). Navarette tied this entry level to novice coders with only one year of experience in his study. My findings corroborate Navarette findings in that these student descriptions of creativity happened early on in my study.

Navarette (2013) classifies the next level of creativity as students describing their use of imagination and incorporating game design elements. This type of creative ideation was also present in my students. For example, Brenna wrote, "It was a team effort because each of us said things that sparked one another's imagination to come up with the idea." Jackson described incorporating an Easter egg into their game: "We came up with the idea that we should make little sprites that we hid in the levels there was one per level." My study differs in that Navarette reported participants exhibiting this level had had two years of experience in coding. While not all of my participants reached this level of coding skill and creativity within the time frame of this study, many of them did.

Navarrete's (2013) third level of creativity included an emotional element to the creative action where students identified satisfaction and pleasure in their creative works.

For my students this was present in many of their reflections. My students described their creativity efforts as “now the game seems more fun and professional” (Brenna), “[their idea] was funny and smart” (Oliver), and “The trivia worked like a charm and now our game is almost done” (Adam)

Navarette (2013) posited that confidence in coding led students to higher levels of creative processing and connected this to the number of years that participants had been in the study. My GT students were able to reach these levels of creativity within one semester. Student satisfaction and positive feelings about the project (Csikszentmihalyi, 1996) further bolstered their perceptions of their creative abilities and allowed them to take further creative risks. This could be attributed to the culture of collaboration in my classroom and specifically to the emergence of student expertise in coding and comfort in seeking help. Student confidence in their coding skills grew as they learned, tested, and shared coding with their peers.

Generating ideas. One element of Torrance’s (1972) definition of creativity is fluency in idea generation. In this study’s qualitative data, students defined creativity as generating ideas, openness to new ideas, and thinking out of the box, which aligns with Torrance’s element well. Idea generation is also a part of the P21 framework calling for students to practice elaboration, refinement, and evaluation of ideas (P21, 2009). Creative solutions are tied to multiple rounds of idea generation and evaluation (Karademir, 2016; Kashani-Vahid et al., 2017; Kaufman, Kornilov, Bristol, Tan, & Grigorenko, 2010). Game design-based learning gave my students an opportunity to engage with their peers in the process of idea generation, evaluation, and refinement.

Ideas was coded 47 times in student reflections about creativity, illustrating the importance of idea generation to students' perceptions of their creativity. For example, Hannah stated, "Our creativity helped us think of new ideas….I am open to more new ideas," and Brenna wrote, "Each of us said things that sparked one another's imagination to come up with the idea." Individual items on the creativity survey support student claims to feeling confident in their abilities to generate multiple ideas for solving problems. The following survey items showed the highest mean gains between pre- and postsurvey:

- "I am confident that I can develop creative ideas for almost any problem." (Mean difference gain = 0.27)
- "When I am confronted with a problem, I can usually find several solutions." (Mean difference gain = 0.22)
- "I have a lot of good ideas during STEAM class." (Mean difference gain = 0.16)
- "I am good at proposing "out of the box" solutions." (Mean difference gain = 0.16)

Students also described the benefits of combining ideas to create something new. For example, Sebastian reflected: "We ended up combining our ideas into a super fun game." Throughout the game design process students had to evaluate ideas and choose the ones that would work best for them as a team and for their final project. Baradaran and Kim (2019) noted that "tinkering, experimenting, (re)creating, (re)formulating, and refining play important roles during the process of generating and advancing ideas" (p. 401). The opportunity to generate and test ideas in the game design-based learning environment gave my students confidence in their creative abilities. This study confirms the findings of several authors (An, 2016; Navarette, 2013; Li, 2010; Sáez López et al., 2016) showing an increase in creativity through game design-based learning.

Crafting narrative. The process of crafting narratives, characters, and conflicts in game design-based learning works to students' advantage in the development of creative thinking (An, 2016; Yang & Chang, 2013). Creation of novel ideas must be balanced with the usefulness of the solution (Beghetto & Karwowski, 2017; Henriksen et al., 2016; Johnson & Johnson, 2014). In crafting narrative, my students were able to work towards finding useful yet novel approaches to the design task while recognizing the demands of game design-based learning (An, 2016).

Data from Theme Three showed that students approached the development of narrative and science integration in various ways. Each group of students used their creativity to construct their own original and personally meaningful interpretation (Beghetto & Kaufman, 2007; Runco, 2008) of the game design task.

Most groups' creativity was represented as a novel and appropriate response (Amabile, 2013) to the challenge. For example, "In the Jungle" by Madison, Katie, and Kevin, had the player searching for and collecting pieces of a map. The audible signal to find the map pieces were either high or low pitch sounds. The obstacle that the player was trying to avoid was a wolf. If the player found all the map pieces, a treasure would be revealed. This game integrated storyline with game elements producing an effective game where students practiced identifying pitch, which directly related to the science content.

Some groups did not achieve integration of narrative and science content. For example, the game "Bat and Centaur" by Sebastian, Shreya and Mira, provided players with an engaging gaming experience that included collection of objects, avoidance of obstacles, and tracking character lives. These students got very caught up in developing the game. However, they missed the point of incorporating science content.

Similarly, An (2016) and Ke (2014) found that some students (over half and 20% respectively) struggled to incorporate their game ideas with content. For these students, content was an afterthought to the game's storylines and game dynamics. In these cases, creative storytelling and game development conflicted with the goal of incorporating content knowledge into their games. If one takes the view that creativity must meet the constraints of the product (Sternberg & Kaufman, 2010), and the usefulness of the solution, (Beghetto & Karwowski, 2017; Henriksen et al., 2016; Johnson & Johnson, 2014) these student games would not be considered creative because they missed the constraints of the task.

Research Question 3: In what ways will a game design-based learning unit impact fourth grade GT students' perception of their collaboration and teamwork skills in science at Cori Elementary School?

The purpose for this question was to explore the impact of game design-based learning on collaboration for GT students. The extant findings on collaboration for GT students is mixed. Recent literature suggests that group work can be difficult for gifted students (French et al., 2011; Kanevsky, 2015). Other studies suggest that when faced with a complex task, GT students respond positively to working in a group (Diezmann & Watters, 1997; Lou et al., 2001; Ross & Smyth, 1995; Winstanley, 2010). Collaboration is emerging as an important skill for learners in order to be ready for college and careers (P21, 2009). To explore the question of game design-based learning's impact on student perceptions of collaboration and teamwork skills, both quantitative and qualitative data were collected. The quantitative results are mirrored in the qualitative data and illustrate the significance of a) finding value in collaboration and b) creating a classroom culture that encourages positive collaborations

Finding value in collaboration. Finding value in collaboration within cooperative groups leads to higher self-esteem and promotes autonomy and independence (Johnson & Johnson, 2014). The qualitative and quantitative data together show students finding value in collaboration through 1) changes in student perceptions about working in groups and 2) exchanges of help.

Changes in the students' perceptions about working groups. Quantitative data were collected from a pre-postsurvey that included ten items on collaboration. Postsurvey scores (*Mdn* = 3.60) were significantly higher than presurvey scores (*Mdn* = 3.40). More specifically, the following survey items reflect growth in reliance on one another:

- "My team relies on each person's skills," had a postsurvey mean of 4.19.
- "When I have a problem or get stuck, I try to work it out by myself," had a postsurvey mean of 2.83. This item was reversed for analysis.
- "I work with my team to monitor our progress on a project," had the highest gains (*M*=3.97, Gain=0.28).

Through this game design-based learning experience, students came to see the benefits of working together. In their reflections, students also shared: "We needed teamwork," (Erin), “it [troubleshooting] required multiple people,” (Diego), and “Our group depended on each other,” (Parker). Hanna shared that her group “[found] out everyone's strengths and weaknesses so everyone could work on what they were good at.” Each of these illustrates a shift in student perceptions and a growth in valuing collaboration.

Data from Theme One illustrates the ways students collaborated to manage the complex task of game design. One important element in changing student perceptions was equitable distribution of work. Students shared how they used levels within their games to assign workload to each person by *picking levels* and assigning *random levels*. Students shared that “everyone did a level” (Tyler), “we would work on different parts,” (Logan) and “And then we just kind of, like, mixed them up …. So, it really wasn’t unfair,” (Hannah). One item from the Collaboration Survey supported these student expressions, with an increase from pre-to postsurvey scores, item 24: “My team shares the workload in a project” (*M* = 4.17, Gain = 0.25).

This study confirms Kim and Bastini’s (2017) findings that game design-based learning helped students to understand and value each other’s skills and reliance on each other grew.

Exchanges of help. Herro et al. (2017) in designing a rubric for evaluating STEAM identified peer interactions including monitoring tasks with peers, dividing work, and peer feedback as important elements for collaborative work. Kafai and Burke (2014) posit that effective participation includes searching out, organizing, and distributing responsibilities. Drawing from Theme Two, the emergence of student expertise grew with information seeking, sharing, and through building and testing code. In particular, the act of co-coding helped pass knowledge from one student to another.

Student statements about seeking help from each other included: “You could ask one of your teamates [*sic*] for help and they will share what they have learned,” (Amanda) and “I needed help from Sebastian for the sound. I chose him because he is really good with sound,” (Shreya). These statements indicate that students grew to see each other as valuable resources for completing their games. While sharing started within project groups, it crossed over to other classroom groups and across the two classes participating in this study. On the Collaboration Survey, Item 19: “When others get stuck, I help by giving directions” decreased by 0.23 from pre- to postsurvey. This may indicate that students recognized the kinds of help they were giving went beyond just directions. These findings corroborate An’s (2016) finding that students from different teams shared ideas and strategies. This study confirms Baytak’s (2009) findings on the importance of sharing strategies, tips, and testing coding with others. Kim and Bastini (2017) also found that in game design-based learning, playtesting games helped with communicating ideas and making decisions. For this study, students engaged in collaborations not only with their teams, but also with other teams in their class, and teams from the other GT class.

Creating a classroom culture that encourages positive collaboration. Through scaffolding my students' efforts, we were able to build a classroom culture that encouraged the emergence of student expertise and raised the level of comfort students felt in seeking out help from one another. Baytak and Land (2011) found that game design-based learning encouraged a climate where students were able to see each other as experts. Their research also indicated the teacher’s role was important in directing students to their peers for solving problems. Robertson and Howell’s (2008) stressed the importance of the teachers' role in facilitating the exchange of knowledge between learners. Other researchers have reported a climate where students turn to each other to solve design problems (Akcaoglu, 2014; Ching & Kafai, 2008). In creating a classroom culture that encourages positive collaboration, two suggestions to be considered are: a) strategies to support collaboration and b) student expectations.

Strategies to support positive collaboration. In the book *Lifelong Kindergarten: Cultivating Creativity through Project, Passion, Peers, and Play*, Resnick (2017) describes the role of the teacher in the Computer Clubhouse environment as moving between roles of collaborator, connector, catalyst, and consultant. I can see how in my role as teacher, I played each of these parts and how this supported positive collaboration in the classroom.

Admittedly, I am not an experienced coder. I went into this project and research with some knowledge of Scratch coding, but I also knew that some of my students may have known more coding than I did. So, we went into this coding adventure together as collaborators. This automatically put me on a search for those students who would be my first experts in the class. I engaged often with the students in searching out coding solutions. For example, when students came to me with coding questions, I would have them bring their Chromebook to my computer station, and we would both search through the Scratch tutorials or the Scratch Wiki. We would try different searches until we found what was needed. Collaborative searching had two impacts. First, students saw me as a learner alongside them (Lave & Wenger, 1991) allowing them to see that if we did not know something, we could always work toward finding an answer or a solution. Second, it allowed me to model (Brown, Collins, Duguid, & Seely, 2007) how to search for information in these environments.

Another way I encouraged students to turn to each other was our class "I have a question board," (see Figure 5.1). It was created in Padlet and students had the QR code and iPads on their tables while they worked. When students had a question, they could scan the code and post the question. Our question board was a place for students to seek help from each other. Even when I did know how to do some piece of coding, I would turn to students to see who could help. Students used the question board to share information about coding. The board was visible on the classroom Smartboard. Oftentimes, students did not respond on the board but went directly to the person who was seeking help. Eventually, students stopped using the board and just started directing each other to the students they saw as experts on particular pieces of coding. For example, Hunter spent a long-time studying coding in other games, He became good at remixing and using the backpack feature in Scratch. Other students went to him when they needed this type of help. In this sense, I acted as a connector, monitoring who had specific skills and connecting them with those who needed the information.

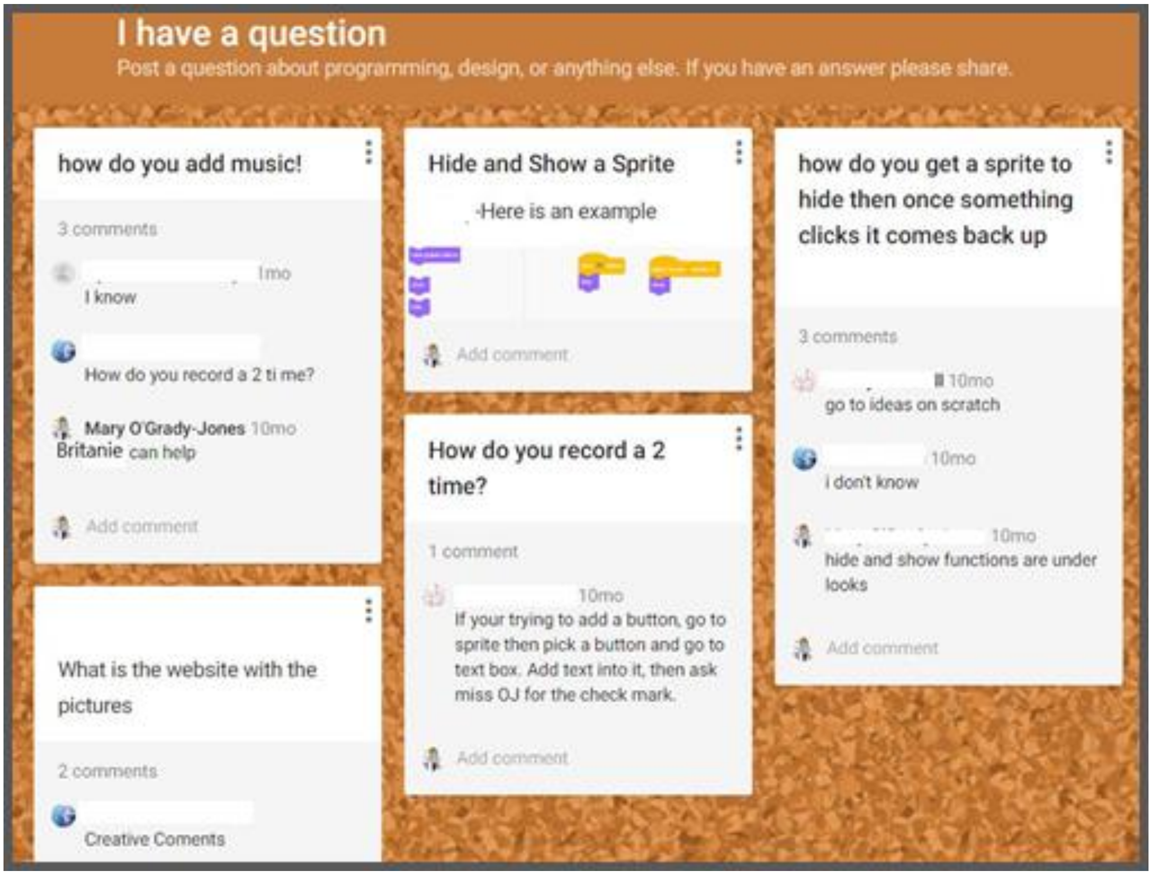

Figure 5.1. Screenshot of our "I have a question" board.

I also made a habit of calling out whenever a student had figured out a new piece of coding. For example, when Eli figured out how to use the if-touching sprite-then sequence, he called me over to show how it worked. I then called out to the class with a quick announcement that let students know they could go to him for this type of help. It was a normal part of my classroom routine to announce to the class when someone has mastered some piece of coding. This practice allowed students to connect with each other when they were stuck with a problem.

As a catalyst, I implemented strategic sharing in small groups. When I knew that a group of students was ready for a specific piece of coding, I called together a small group of students from different game groups. For example, at one point, I knew that several students needed to know how to create a reset function that would set their characters and backdrops back to the beginning. I called together a small group, helped these students build the coding, and then released them with the instructions to pass this on to the rest of their group. This provided a cluster of students who could turn to each other if they were unsure about a step in the process.

Acting as a consultant, I was able to monitor where students were in terms of their projects and provide support in helping them connect with resources. Each of these strategies helped students to see themselves as emerging experts and led to positive collaborations throughout the course of the study. Building a classroom culture of collaboration meant shifting my role to connector, connector, catalyst, and consultant. Thus, providing a space where students were excited and eager to share what they were working on and they were willing to share new knowledge.

Student expectations. For my students identifying peer experts became a routine part of our day and served as an effective way to seek and share coding solutions. During member checking when I explained building a culture of collaboration, Hannah looked at me with a bit of confusion on her face and stated, "That's just what you expect of us. We have to help each other." The other students all agreed that this was just a part of being in my class. Setting up student expectations of working together and helping each other was facilitated by our shared quest for coding knowledge. This process made my classroom more egalitarian. As the teacher, I was not considered the only expert in the class. Student ownership of expertise was distributed throughout the class and help was shared across groups. In my classroom, students knew when they were free to move about the room and seek out what they needed to complete their work. This freedom combined with high expectations for quality work, made our classroom environment flexible and open to student's collaborative efforts. The game design-based learning experience strengthened my students' perceptions of their collaboration and teamwork skills.

Research Question 4: Will game design-based learning improve knowledge of light and sound concepts for fourth grade GT students at Cori Elementary School?

Previous game design-based learning studies have looked at gains in science knowledge (Baytak & Land, 200 Ching & Kafai, 2008; Khalili, 2014; Kafai & Ching, 2001). These studies looked at science talk (Kafai & Ching, 2001) and presentation of science concepts in games (Ching & Kafai, 2008; Khalili, 2014). The main sources used to answer this question were the pretest and posttest results, student reflections, and information from student's games.

Students took an objective pre- and posttest on light and sound concepts. The test contained 18 multiple choice questions covering grade level science standards. For this study, student science test scores rose from pretest (*Mdn* = 14.00) to posttest (*Mdn* = 16.00). Posttest scores were significantly higher than pretest scores ($Z = 5.02$, $p < .001$), which demonstrated positive effects on student learning.

Findings from other studies did not examine quantitative results for content knowledge but instead relied on qualitative findings. For example, An (2016) found that only half the participants integrated content into their games, and Ke (2014) found that 20% of participants did not include intended content. For this study four of the fifteen games had limited or entirely lacked science content. Ke (2014) looked at the instances of math talk in game designers and found that only 20% of design time was spent talking about math concepts. This is mirrored in my data in that students spent more time talking about story, characters, setting, and game mechanics, however, I have no frequency data to quantify the proportions.

Some of my participants reported wanting the game to be "realistic." Their games revolved around characters needing "help with homework" and "[forgetting] study guide at home." One student reported the desire for the game to be scientific saying, "my bin [for sorting objects] was more scientific so that is why I disagreed with [the] box because it didn't match science." Students also chose backdrops or settings to support their desire to be realistic or scientific. These included: house (4), science lab (2), and school (1).

Three groups incorporated science term definitions into their games. This was done through having a character explain the term or through a character providing a hint to the player. The following statements are examples of terms found in games:

> Well, you can't see through me [an apple] because I am opaque, and light won't pass through me. And, you can see through me [a glass] because I'm transparent and light will pass through me. ("Betty and Mr. Chicken")
>
> Translucent is when you can see a little light through the object, transparent is when you can see all the light through the object and opaque is when you can't see ANY light through the object. ("A Walk by the Sea")
>
> In case you didn't remember refraction is when light bounces off water and the thing in the water looks like it's broken. ("Light Game")

Many groups used quizzing or requiring an answer to a question to move on in the game. Six games focused on the light properties, including translucent, transparent, and opaque. Three games focused on the sound concepts of pitch and volume. Three games included questions on both light and sound. Two of the remaining groups included no science content and only one question about light and one group did not include any science content at all.

Sample light questions from games:

- Is air translucent, transparent, or opaque?
- Is a teddy bear opaque?
- Is the glass translucent, transparent, or opaque?
- What happens when light reflects?
- Is white light really white?
- What makes your shirt look a certain color?

Sample sound questions from games:

- Was that a low or high pitch sound?
- Is sound a form of energy?
- Do tiny sound waves make a low sound?
- Is an echo made by sound waves?

Students approached the task of including science concepts into their games in various ways developing quiz games, sorting games, and narrative games that wove the science content into their stories. Five groups used a quizzing approach where the player had to answer science-related questions in order to move from level to level. Three groups developed games where the player had to sort transparent, translucent, and opaque objects. Four games centered around a narrative that involved learning about and practicing light and sound concepts. For the majority of my participants, science remained a focal point for their games. Their explanations and questions in their games demonstrated their understanding of the science concepts.

Summary

This discussion was organized by the four research questions covering problem-solving, creativity, collaboration, and science knowledge. This study confirms the findings of previous studies in demonstrating gains in solving decision-making problems (Akcaoglu, 2014), design problems (Ke, 2014), and troubleshooting problems (Akcaoglu, 2014, 2016; Akcaoglu & Koehler, 2014). While quantitative data for creativity did not show significant changes, students' reported experiences demonstrated growth in creativity. Growth in creativity was shown through a nurturing environment (Navarette, 2013), generation of ideas (An, 2016; Navarette, 2013; Quing Li, 2010; Sáez López et al., 2016), and crafting narrative (An, 2016; Yang & Ching, 2013). Growth in collaboration was supported by both quantitative and qualitative data, thus confirming previous studies that found game design-based learning lead to student recognition of the importance of finding value in collaboration (Kim & Bastini, 2017), and the teacher's role in creating a classroom culture that encourages positive collaboration (Akcaoglu, 2014; Ching & Kafai, 2008). This study showed positive gains for science knowledge from pretest to posttest. Similar to Ke (2013) and An (2016) this study found that some students did not include intended content into their games. For this study, 80% of the groups effectively integrated science concepts into their games.

Implications

This research has implications for me, for practitioners in both STEAM and GT, and researchers. Three types of implications are discussed a) personal implications, b) implications for game design-based learning in STEAM, and c) implications for future research.

Personal Implications

Reflecting on my personal growth throughout this study, three areas strike me as having particular importance: 1) conducting in-depth review of the literature to support proposed action, 2) being systematic about the collection and analysis of both qualitative and quantitative data, and 3) seeing myself as not only a teacher but also a scholarly practitioner.

Conducting in depth review of the literature. So much of what I see in terms of STEAM or technology lessons are flashy, eye-catching, and fun-looking. It is important to view these with a critical eye. Particularly when embarking on a larger project, such as project-based learning or game design-based learning, the planned instruction's meaningfulness should be considered because of the investment of time and effort. Some questions to be considered include:

- Does the project meet academic, social, or personal needs of the students?
- Is the problem worth taking on?
- Is there research to support the use of an innovation?

As I began forming my initial research questions, I had an idea about using games or game design in the classroom. My ideas were a result of my experiences, but that alone is not enough to justify making changes to the curriculum. A review of the literature allowed me to understand game design-based learning and how it fits into the broader scope of project-based learning. Reading past research allowed me to understand what had been done in the past and how other researchers measured change in their participants. The literature on collaboration, creativity, and problem-solving guided both my qualitative and quantitative instruments.

In addition, the literature on GT students helped me to gain a deeper understanding of my students' needs. Some of these understandings supported my knowledge and others presented new topics for me to think about as I moved through the planning and implementation of my innovation. Constructionist theory (Harel & Papert, 1991; Kafai & Resnick, 1996) helped me to frame the learning experiences that I was designing for my students. Pulling together what is known about game design-based learning, constructionism, project-based learning, GT, and 21st century skills gave me perspectives on which to base both my research design and my findings, thus highlighting the interdisciplinary nature of knowledge (Renzulli, 2016).

One important skill I believe that I have gained has been the ability to discern between opinion pieces and empirical research. In the field of education, there exists an abundance of opinion pieces that attempt to pass as scholarly. I now see these as anecdotal and in need of further scrutiny.

Systematic collection and analysis of data. Data-driven decision-making has become a part of initiatives in K12 education. In my prior experience, this meant looking at student test scores and making decisions on how to remediate mistakes or misunderstandings. I have always felt that it is hard to correct a mistake, if you do not know what mistake was made. Identifying students' misconceptions is hard to do with just numerical data. Content knowledge can be complex, and it requires more than just quantitative data to understand the nuances of student thinking. My study looked at student perceptions of their abilities in problem-solving, creativity, and collaboration. While the quantitative data provided a specific snapshot of what was happening, student voices collected through qualitative methods were invaluable to understanding what students were thinking (Creswell, 2014) at various stages of the innovation. It was important to analyze data that were purposefully and systematically collected. Taking time to analyze the data by digging deeper, thinking more critically, and stepping outside my own views to see through other lenses enabled me to have a deeper understanding of how my students grew as 21st century learners. I understood their strengths and weaknesses, their fears and frustrations, their challenges and triumphs. Triangulating various points of data gave me a better understanding of student growth and use of 21st century skills along with a full and nuanced picture of my students. As I move forward as a teacher and scholar, I will continue to see the value of systems to collect and analyze both qualitative and quantitative data.

New vision as a teacher and scholarly practitioner. The skills and knowledge that I have gained throughout the course of this work have given me a new vision for myself as a teacher and scholarly practitioner. I read research with a more critical eye. I question trends with a more focused intensity. I have become keenly aware of the impact of my decisions on student learning. Student expertise should be valued in student collaboration. The impact of how student experts contribute to overall student learning is worth consideration in areas beyond coding. Allowing students to master and share knowledge gave my students a sense of belonging to a learning community where it was alright to not have all of the answers (Zawilinski, 2016). This made me rethink some of my teaching methods and seek other opportunities to grow in my own expertise. In STEAM, we refer to the design cycle, where the first steps are to ask and imagine (Engineering is Elementary, 2017). If I only provide opportunities where students follow scripted procedures, as many science lessons at the elementary level are, students never truly have the opportunity to be guided by their own questions or find solutions using their imagination. Shifting to a more collaborative and creative classroom environment more clearly aligns with the vision of 21st century skills for college and career readiness.

I have begun the process of sharing my findings with our technology leadership at the district level. Also, I shared with the technology learning community at one of our monthly meetings.

Implications for Game Design-based Learning in STEAM

This study has implications for game design-based learning as a part of STEAM learning. There is potential for future collaboration with classroom teachers and GT teachers. STEAM is a part of our related arts rotation at my school, giving me a unique opportunity to seek out joint projects and open others to new ideas. Implications for game design-based learning in STEAM include a) flexibility in the curriculum, b) opportunities for collaboration with GT and classroom teachers, c) student feedback and internal motivations, and d) a playground for practicing 21st century skills.

Flexibility in the curriculum. The flexibility in my curriculum is not indicative of other teachers' curriculum pressures. As I embarked on this study, I was a GT classroom teacher with the responsibility of teaching all subjects. I am currently a STEAM teacher and work in a support role for classroom teachers by incorporating among other things science and technology as a part of the related arts program at my school. As a STEAM teacher, I am bound by state computer science standards. This affords me a great amount of freedom in what projects I choose to tackle with my students. This freedom allowed me to take an entire semester to teach game design-based learning. I had considerable support from the classroom teachers who did the groundwork of teaching light and sound concepts to our students. While we reviewed, discussed, and experimented with light and sound concepts, our focus was applying this knowledge to a game setting. Game design-based learning gave me the opportunity to collaborate with classroom teachers in reinforcing science concepts while exploring and enacting computer science standards.

Opportunities for collaboration with GT and classroom teachers. In addition, collaboration with classroom teachers may alleviate some of the scheduling issues that were encountered during this study. My schedule allowed me to meet with each class every seven school days. At the beginning of the study, establishing and remembering usernames and passwords was a struggle. This issue was addressed using a recording system for usernames and passwords, but initially, it caused much lost time. In addition, I found that recapping discussions of where they were and what needed to be done took more time than planned for in the schedule. Students had to re-engage themselves back into the project after long periods of time when they often lost focus of their project goals. Another issue was that as coding skills were learned, they had to be stored for several days before they could be enacted and practiced. Perhaps some collaboration with the classroom teachers would allow for students to continue working on projects between STEAM class periods. As student experts evolve, collaborating teachers could be relieved from some of the pressure of knowing how to code.

Student feedback and internal motivations. It should be noted that in my school, STEAM classes are not graded. This was both freeing for some students and a struggle for others. For many students, the freedom to explore and create a group project that did not have the pressure of a grade attached was a good experience. Other students demonstrated the need for the added external motivation of a grade to keep them moving forward on the project. This may also be attributed to the fact that in the past, projects in the STEAM classroom were limited to learning that could be done in one class period. STEAM project that span multiple periods and weeks was new. This is a shift in vision for what STEAM can be through the related arts lens.

A playground for practicing 21st century skills. Design activities allow students to test boundaries, play with ideas, and explore possibilities (Resnick, 2006). Game design-based learning served as a playground for practicing 21st century skills. Building a culture of collaboration and space for creativity was an important part of the success of game design-based learning. Students need environments where they can practice these skills and improve their efforts. Game design-based learning was important for my GT students in terms of growth in their perceptions of their abilities to problem-solve, act creatively, and collaborate. For the time frame of this study, I was presented with a unique situation having two GT classes that traveled to related arts together. Renzulli (2012) puts forth an expanded definition of giftedness to include creative productive giftedness and calls for programming that moves beyond content acquisition towards developing the talents of all students. Game design-based learning provides an engaging environment where all students can practice problem-solving, creativity, and collaboration.

Game design-based learning provided my students rich opportunities to tackle various kinds of problems including decision-making problems, design problems, and troubleshooting problems. My students found these problems engaging and worth solving as evidenced by their responses and reflections. Decision-making problems required students to share, evaluate, and come to consensus on their ideas for the game. As students began building their games, they faced design problems. Students were able to tinker within Scratch (Resnick, 2006, 2014, 2017) and test out various design elements. They pushed boundaries as they learned more coding and were able to add more complex game mechanics to their projects. Through troubleshooting their coding, students had to analyze the systems they had built in order to fix problems. Student creativity was nurtured through the entire game design-based learning process. Students were engaged in idea generation, storyline development, and game design. Collaboration results for this study suggest that giving students the opportunity to share expertise helped develop a culture in my classroom where sharing information was the norm. Through co-coding students passed coding knowledge from student to student and group to group.

Implications for Future Research

The findings of this study have implications for my next cycle of action research and for those who wish to explore game design-based learning within a STEAM setting. It is important to continue to explore the ways that GT students can be supported in their growth in creativity, collaboration, and problem-solving within science curriculum. The impact of game design-based learning on various domains of giftedness would be worth further exploration. On the same token, *all* students need to be supported in these endeavors as well. While I have found that my students collaborated well and sought each other out for needed information, can these same behaviors be documented in a heterogeneous classroom? If GT students are already seen by their peers as experts in other subject areas, is there room for new experts to arise in the coding arena? This is an opportunity for further study.

Another area that I am interested in exploring is the evolution of a game design-based learning curriculum that could be introduced over several years. See Figure 5.2. Game design is complex, involving the mechanics of game play, storyline, and coding. For my students, scripted coding lessons they did in the past led to projects that all looked the same and skills that were not transferred. I found that student-driven coding led to ill-structured problems (Jonassen, 2009) with different solutions. A simple example would be the ways that students managed the movement of sprites in their games. There was no one right way to do this and students created their coding solutions based on what they wanted for their games. Beghetto (2017) posits that “uncertainty can serve as a catalyst for creative thought and action” (p. 987). Game design-based learning could put a structure in place for students to explore the uncertainty of ill-defined problems. Coding allows for creativity and problem solving through tinkering, pushing boundaries, and troubleshooting.

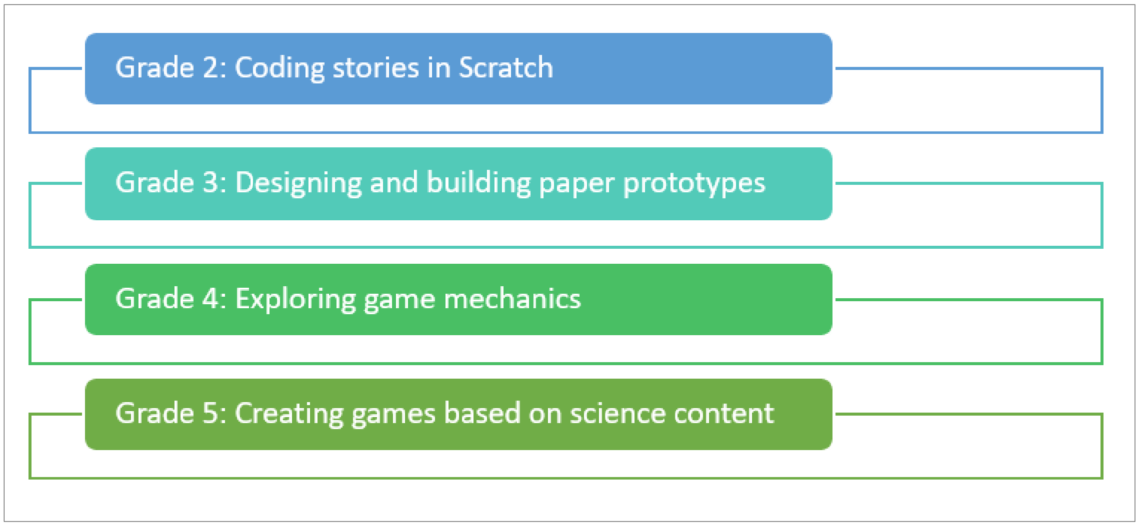

Figure 5.2. Proposed Game Design-Based Learning curriculum.

Storyline played an important role in the design process for many of my students. A game design-based learning curriculum could provide students with some necessary scaffolding for their growth as game creators, coders, and storytellers. I am currently working with second graders using Scratch to code a weather story, allowing students some early experience with coding and integrating science into their stories. Third graders are designing and developing paper prototypes of games giving them the opportunity to explore the game rules, mechanics of play, and gaming interactions. Fourth graders are exploring game mechanics in Scratch. These students did paper prototyping as third graders. Fifth graders could then design and build games that incorporate science content. Spreading out the cognitive load (Sweller, van Merrienboer, & Paas, 1998) necessary for game design may help students gain new skills each year that naturally grow into the next level. This can also remove the intensity of completing all game elements in one year and would create room in the STEAM curriculum for topics and pedagogy other than game design-based learning.

In putting together a game design-based learning curriculum, students would have the opportunity to grow as experts in a community of learners (Wegner, 1987). Much like the craft guilds of the past, student experts could pass knowledge on to apprentices with the goal of moving all members forward.

Limitations

In exploring the limitations of the study, three items were brought to fore. These include the limitations of action research, data limitations, and scheduling limitations. Action research is designed to answer specific problems of practice within a specific setting (Mertler, 2017). In the study, I had to act as both the researcher and the implementer. This dual role was challenging and may have caused me to miss some interactions in the classroom while I was busy managing the classroom and helping students with coding. Another limitation was in the sample size. This study included 46 students in two GT classes. Both classes were part of the innovation group, and there was no control group with other GT students for comparing gains in regard to problem-solving, creativity, collaboration, and science knowledge. For all these reasons, this action research and this study while providing insight, cannot be generalized. So, any insights beyond the current context remain with the reader.

Data limitations include issues with both qualitative and quantitative instruments. In student reflections, there were no specific prompts about science content. Students did not share any reflections on the challenges of integrating science concepts into game design. Providing students with a prompt that asked about integrating science into their games would have provided additional insight into students' understanding and their decision-making process for the task. The qualitative data from the collaboration reflection question is less strong; it had only 20 students respond. The lack of response had two causes. First, state testing had begun, and students and teachers were occupied with that task. State testing also limited student access to technology. Second, I had to leave the research site due to a family emergency. Upon my return, finishing final reflections and completing the focus group interviews took precedence over tracking down missing collaboration reflections.

In the area of creativity, there were some discrepancies between the qualitative and quantitative data. The Creativity Survey was divided into two parts. Creative self-efficacy in science had a reliability of Cronbach's alpha = .71, which is acceptable. While the qualitative data showed positive results for creativity, mean scores dropped from 19.56 to 19.36 on a scale of 25 from presurvey to postsurvey. This may have been caused by a mismatch between survey items and student perceptions. There are multiple methods for measuring creativity and creative potential. This study looked specifically at student perceptions and self-efficacy. Student actions were judged to be creative by the students and their peers. Additional research in this area may be needed.

This study also presented some scheduling limitations. Unlike previous studies in game design-based learning (e.g., Akcaoglu, 2013; Baytak & Land, 2010; Khalili, 2014), the time frame for this study was sometimes irregular. Our related arts schedule allowed me to meet with each class for 45-minute periods on a seven (school) day schedule. Sometimes this meant that I did not see students for nine to eleven days because of weekends. This led to many stops and restarts for student progress and may have led to some of the inconsistencies in data.

Closing Thoughts

Reflection is an integral part of action research (Mertler, 2017) and calls on those who engage in it to be reflective of their own practice. Jonassen et al. (2003) defined problems as the unknown and posited that the finding of the unknown must have some social, cultural or intellectual value. They asserted, “if no one believes that it is worth finding the unknown, there is no perceived problem” (Jonassen et al., 2003, p. 20). My quest for the unknown began as a hero’s journey (Campbell, 1990), a call to action. I was tired of the way technology was being integrated into our GT curriculum. Apps were replacing projects and digital text was replacing textbooks. This was never my style of teaching or learning. With technology’s infinite potential, we were continuing to allow students to be consumers of information rather than creators of new and novel works (McDooley et al., 2016; Sáez López et al., 2016). I have long used various games for learning, finding the immersion in a game world compelled my students to greater understandings. It was in the combination of realizing the potential of students as creators and the learning I was seeing as my students were immersed in game worlds that I found my unknown.

While there is an increase in state and local mandates and a curriculum that increasingly leaves teachers feeling boxed in, within that box is an infinite universe of possibilities allowing for creativity, collaboration, and problem-solving. Good teachers recognize that the answer is not the goal. The goal is the process, the journey, the learning along the way. Real-world problems are not solved instantly. Problem solvers need to make mistakes, follow potential solutions, and learn from them. Flashes of insight come after sitting in the uncomfortable in-between, knowing there is a potential for answers.

The very best of teaching is in tinkering, pushing boundaries, and troubleshooting in the classroom. Tinkering happens every time a teacher looks at content and thinks of ways to make it more engaging and more relevant to students. Teachers are always pushing boundaries when they combine their knowledge with a vision for what could be, producing learning experiences that are transformative for their students. Troubleshooting happens every time a teacher analyzes the system to fix what is not working for one student or multiple students.

So faced with the challenge, my students joined me in this quest, and we passed into the unknown, trusting each other that this would be good. The knowledge of constructionism, project-based learning, and game design-based learning combined with my vision of what could be possible allowed me to provide students with structure, accountability, and remarkable freedom. All the while, I was nurturing their quest to tackle big ideas with imperfect answers. On the sidelines, I tinkered with content, pushed boundaries of what we all thought was possible, and engaged in troubleshooting all the things in the system that needed adjusting by putting mechanisms in place for organization, management, and accountability. I have always focused the lens of the camera on my students and the work that they do. I have been a tireless advocate of magnificent things they have done because they have done magnificent work. And my students produced magnificent work. I am in awe not only of their efforts but of their accomplishments. The day they shared their work with our first-grade audience was energizing and inspiring.

Every hero's journey ends in transformation. During this action research project, the data I collected was noted by my adviser as demonstrating exemplary collaboration among the students in my classroom. He asked me to write about what I was doing. Being asked to analyze what seems to me as just a part of who I am is both an odd request, and a difficult task. It is flattering, embarrassing, and difficult to manage as a researcher. He only saw the data that I collected from the classroom I taught in, and it's a little weird and embarrassing to take that as a compliment. But it is data. And somebody who never saw my classroom recognized it not because of an observation but because of the data that were collected. I have been able to create freedom and flexibility despite the increasing constricting levels mandated by districts and legislators. I am not the only one who can do this. There are likely countless numbers of teachers who are able to create spaces where collaboration, creativity, and problem-solving can flourish. I have learned enough about research and research methodology to know that opinion alone cannot drive theory. Having said that, there would appear to be value in studying teachers with the skills that are able to create these spaces for learning — not for the purpose of developing another taxonomy of skills for teachers. But it may be possible to compile enough powerful data to provide others inspiration to try it on their own.

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APPENDIX A

INFORMED CONSENT LETTER

UNIVERSITY OF SOUTH CAROLINA

CONSENT TO BE A RESEARCH SUBJECT

Impact of Game Design-Based Learning on Gifted Elementary Students

As part of our everyday instruction in STEAM class at [redacted], your student is invited to participate in a research study conducted by Mary K. O'Grady-Jones under the direction of Dr. Michael M. Grant (michaelmgrant@sc.edu) at the University of South Carolina. I am a doctoral candidate in the Doctor or Education in Curriculum and Instruction with emphasis in Educational Technology. The University of South Carolina, Department of Educational Studies is sponsoring this research. The purpose of this research is to describe the impact of digital game building on fourth grade gifted students' growth in problem solving, creativity, and collaboration at [redacted]. Your student is being asked to participate in this study because he/she is in fourth grade and in the gifted and talented program.

In STEAM class, your child will:

- Explore existing video games and the elements that make them successful
- Work with a team to design and build your own computer game using Scratch
- Complete assignments in an online design journal including game design decisions and reflection questions.
- Test your game with other students to get feedback and suggestions for improvement.
- Some students will be asked to participate in a focus group to answer questions about the process and their work in creativity, problem-solving, and collaboration.

Within the focus group interviews, others in the group will hear what your student may say, and it is possible that they could tell someone. The researchers cannot guarantee what you say will remain completely private, but the researchers will ask that you, and all other group members, respect the privacy of everyone in the group.

All student responses and reflections will be confidential. Student names will be changed to protect their identities. Research data will be kept in password protected files to ensure confidentiality.

Participation in this research study is voluntary. Your student is free not to participate in the focus group interview or he or she may stop participating at any time, for any reason without negative consequences. You may also choose for your student's STEAM class data not to be used as part of the study. In the event that your student does withdraw from this study, the information he or she has already provided will be kept in a confidential manner. If you wish to withdraw from the study, please call or email the principal investigator listed on this form.

I have been given a chance to ask questions about this research study. These questions have been answered to my satisfaction. If I have any more questions about my participation in this study, or a study related injury, I am to contact Mary K. O'Grady-Jones at [redacted] or email [redacted].

Questions about your rights as a research subject are to be directed to, Lisa Johnson, Assistant Director, Office of Research Compliance, University of South Carolina, 1600 Hampton Street, Suite 414D, Columbia, SC 29208, phone: (803) 777-6670 or email: LisaJ@mailbox.sc.edu.

I agree for my student to participate in this study. I have been given a copy of this form for my own records.

If you wish your student to participate, you should sign below.

Signature of Student/ Participant	Date
Signature of Parent/ Guardian	Date
Signature of Qualified Person Obtaining Consent	Date

APPENDIX B

CREATIVITY AND COLLABORATION SURVEY

Thank you for taking this survey. I am interested in how you view your ability to be creative in general, but also in STEAM class. I am also interested in how you collaborate or work with others while working through challenges. Your answers are private, and I will not know what each of you answered.

The first section asks 15 questions about creativity. The second section asks 10 questions about collaboration or working together.
Thank you for taking the time to answer these questions.

1. Creativity

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am a creative person.					
I am good at coming up with new ideas during STEAM class.					
When I am confronted with a problem, I can usually find several solutions.					
I have a lot of good ideas during STEAM class?					
I trust my creative abilities.					
I am good at coming up with new ways of finding solutions to science problems.					
I am good at coming up with my own science experiments.					
I am good at solving complicated problems.					
I have a good imagination during STEAM class.					
I can solve problems skillfully even complicated problems					
Compared to my friend my ideas are outstanding					
Many times I proved I can find at least one solution for any difficult situation.					
I can deal with problems requiring creative thinking I					
I am good in proposing "out of the box" solutions					
I am confident that I can develop creative ideas for almost any problem					

2. **Collaboration (Teamwork)**

Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
When I have a problem or get stuck, I try to work it out by myself.	⬭	⬭	⬭	⬭	⬭
When I get stuck on a challenge, other members of my class help me by giving me directions.	⬭	⬭	⬭	⬭	⬭
When I get stuck, others step in and fix the problem for me.	⬭	⬭	⬭	⬭	⬭
When others get stuck, I help by giving directions	⬭	⬭	⬭	⬭	⬭
When others get stuck, I just fix the problem for them.	⬭	⬭	⬭	⬭	⬭
I work with my group to identify goals for a project.	⬭	⬭	⬭	⬭	⬭
I work with my team to monitor our progress on a project.	⬭	⬭	⬭	⬭	⬭
My team relies on each person's skills.	⬭	⬭	⬭	⬭	⬭
My team shares the work load in a project.	⬭	⬭	⬭	⬭	⬭
I check with my team to make sure my work is accurate.	⬭	⬭	⬭	⬭	⬭

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https://docs.google.com/forms/d/1xv57J0P7AhtoxnKA0EAN_lT3b_5ggKAg4dlOpKdL7aA/edit?usp=sharing

APPENDIX C

SOUND AND LIGHT ENERGY ASSESSMENT

Light and Sound Knowledge

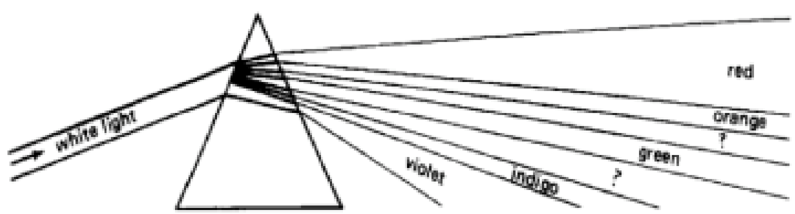
* Required

1. Light is a form of __________ and is made of ____________ *

Mark only one oval.

- energy, many colors.
- heat, particles
- sound, atoms
- gas, molecules

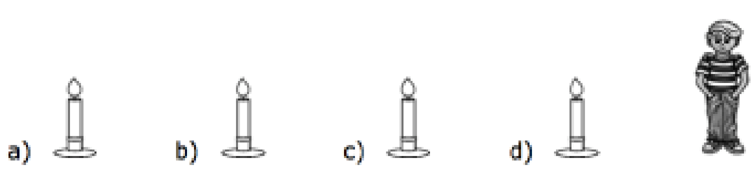
2. White light is made up of every color of the rainbow. In order from red to violet, which two colors are missing from the diagram below? *



Mark only one oval.

- blue and purple
- orange and blue
- yellow and blue
- yellow and purple

3. Which statement is true when interpreting the diagram below. *



Mark only one oval.

- Light source "A" will have a greater intensity because it is farther away
- Light source "D" is more intense than "B" because it is closer.
- The boy sees all flames with the same intensity.
- The boy sees the light from source" A" brighter than source "C."

4. Which of the following items do not give off light on their own?

Mark only one oval.

- ◯ fire and flashlight
- ◯ mirror and walls
- ◯ sun and computer screen
- ◯ sun and stars

5. Which word describes a clear glass plate

Mark only one oval.

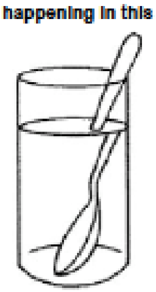
- ◯ opaque
- ◯ translucent
- ◯ transparent
- ◯ mirrored

6. In order to be visible, which object reflects light?

Mark only one oval.

- ◯ candlelight
- ◯ flashlight
- ◯ moon
- ◯ sun

7. Which statement best explains what is happening in this picture?

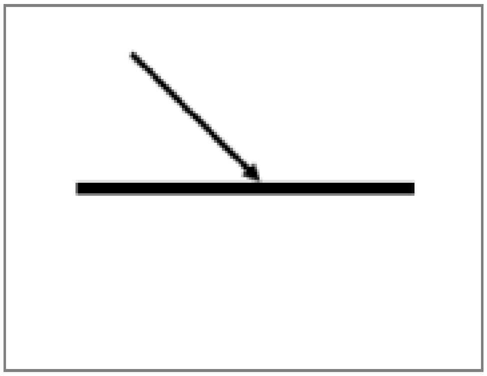


Mark only one oval.

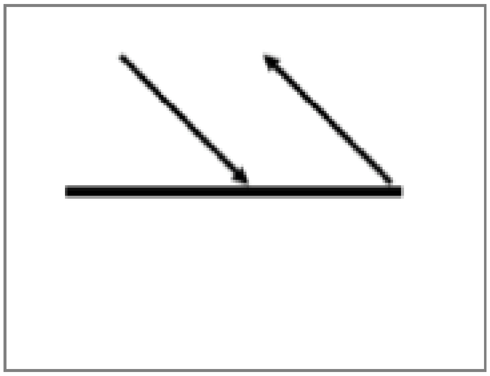
- ◯ The light is being ---reflected -----which makes the spoon appear broken.
- ◯ The light is being ---refracted---- which makes the spoon appear broken.
- ◯ The light is being ---absorbed---- which makes the spoon appear broken.
- ◯ The light is being ---transparent--- which makes the spoon appear broken.

8. **A beam of light strikes a mirror. Which figure best shows how the light will reflect?**

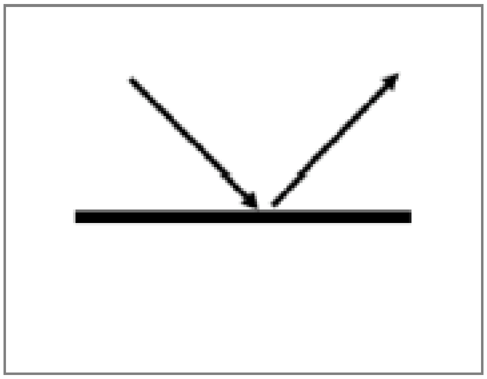
Mark only one oval.



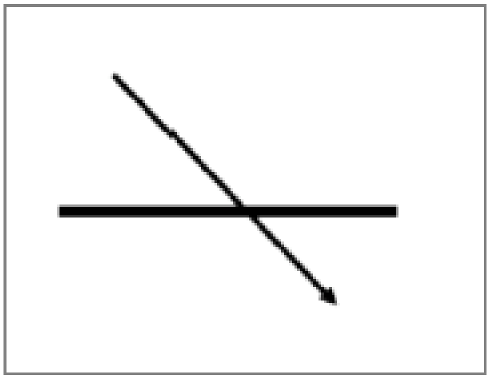
Option 1



Option 2



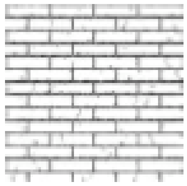
Option 3



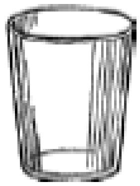
Option 4

9. **Which object is opaque?**

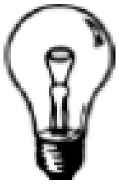
Mark only one oval.



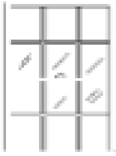
◯ brick wall



◯ drinking glass



◯ light bulb



◯ window

10. **When light shines on a pink flower, the color pink is bounced to our eye and all the other colors are ________ by the flower.**

Mark only one oval.

◯ absorbed
◯ dimmed
◯ refracted

11. **Sandia was making an observation and recorded that the material she was using would only allow some light to pass through. Sandia concluded that the material must be ____________.**

Mark only one oval.

◯ mirrored
◯ opaque
◯ translucent
◯ transparent

12. **How will the sound of a guitar differ after having its strings made very tight?**
Mark only one oval.

- ◯ The pitch of the sound will be higher.
- ◯ The pitch of the sound will be lower.
- ◯ The volume will be louder.
- ◯ The volume will be softer.

13. **How will the sound of a piano differ if it is played with more force?**
Mark only one oval.

- ◯ The pitch will get higher.
- ◯ The pitch will get lower
- ◯ The volume will get louder.
- ◯ The volume will get softer.

14. **Madison plays the drums in the school band. Sometimes she hits the drum gently and it makes a soft sound. Sometimes, she hits the drum hard, and it makes a loud sound. What is the difference between the two kinds of sound she makes?**
Mark only one oval.

- ◯ the direction
- ◯ the pitch
- ◯ the volume
- ◯ the thickness

15. **Tyrone plucks two strings of a violin. The first string makes a low pitch, but the second string makes a high pitch. What does this tell you?**
Mark only one oval.

- ◯ the first string is producing faster vibrations
- ◯ the second string is producing faster vibrations
- ◯ the two strings are vibrating at the same speed
- ◯ none of the above

16. **If you and your friend were on the moon, you could not hear him, even when he shouted. Why would no sound reach you from your friend?**
Mark only one oval.

- ◯ The moon is too small to transmit vibrations.
- ◯ The moon is not solid and cannot transmit sound.
- ◯ The moon's craters block the vibrations from being transmitted.
- ◯ The moon has no air to transmit the vibrations.

17. **Below is a chart of how FAST sound travels through different mediums (or solids, liquids, and gasses).**

Medium	Classification	Speed of Sound (meters/ second)
Steel	Solid	5500
Sea Water	Liquid	1500
Air	Gas	400

Mark only one oval.

- sound travels at the same speed through all mediums
- sound travels fastest through solids
- sound travels fastest through liquids
- sound travels fastest through gasses

18. **Which of the following properties of sound is determined by the speed of the vibrations creating the sound?**

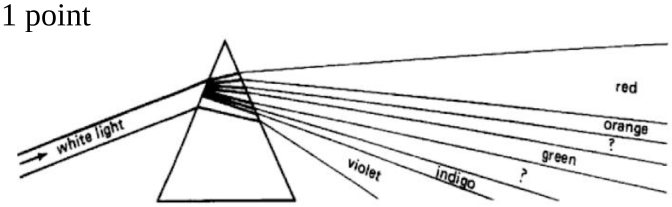
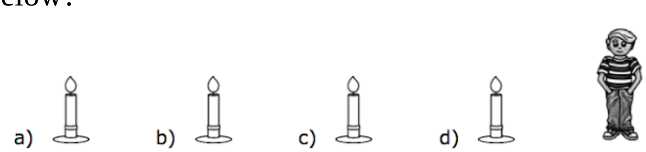
Mark only one oval.

- pitch
- speed
- volume
- wavelength

APPENDIX D

SOUND AND LIGHT STANDARDS ALIGNMENT

Table D1. *Alignment of State Standards with Assessment Questions*

State Standard	Assessment Question
4.P.4A. Conceptual Understanding: Light, as a form of energy, has specific properties including color and brightness. Light travels in a straight line until it strikes an object. The way light reacts when it strikes an object depends on the object's properties.	Light is a form of ___________ and is made of _____________ A. energy, many colors. B. heat, particles C. sound, atoms D. gas, molecules
4.P.4A.1: Construct scientific arguments to support the claim that white light is made up of different colors.	White light is made up of every color of the rainbow. In order from red to violet, which two colors are missing from the diagram below? 1 point  A. blue and purple B. orange and blue C. yellow and blue D. yellow and purple
4.P.4A.2: Analyze and interpret data from observations and measurements to describe how the apparent brightness of light can vary	Which statement is true when interpreting the diagram below? 

as a result of the distance and intensity of the light source.

A. Light source “A” will have a greater intensity because it is farther away
B. Light source “D” is more intense than “B” because it is closer.
C. The boy sees all flames with the same intensity.
D. The boy sees the light from source” A” brighter than source “C.”

4.P.4A.3: Obtain and communicate information to explain how the visibility of an object is related to light.

Which of the following items do not give off light on their own?

A. fire and flashlight
B. mirror and walls
C. sun and computer screen
D. sun and stars

4.P.4A.4: Develop and use models to describe how light travels and interacts when it strikes an object (including reflection, refraction, and absorption) using evidence from observations.

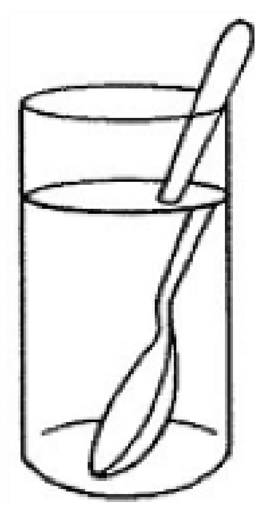
When light shines on a pink flower, the color pink is bounced to our eye and all the other colors are ________ by the flower.

A. absorbed
B. dimmed
C. refracted

In order to be visible, which object reflects light?

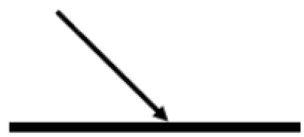
A. candlelight
B. flashlight
C. moon
D. Sun

Which statement best explains what is happening in this picture?

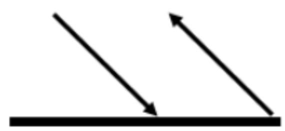


A. The light is being ----reflected ------which makes the spoon appear broken.
B. The light is being ----refracted---- which makes the spoon appear broken.
C. The light is being ----absorbed---- which makes the spoon appear broken.
D. The light is being ----transparent---- which makes the spoon appear broken.

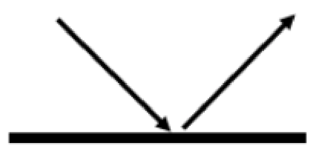
A beam of light strikes a mirror. Which figure best shows how the light will reflect?



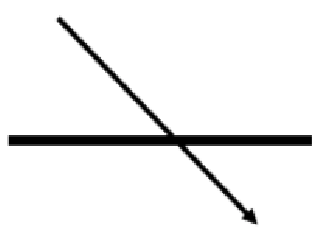
A.



B.



C.



D.

Sandia was making an observation and recorded that the material she was using would only allow some light to pass through. Sandia concluded that the material must be _______________.

A. mirrored

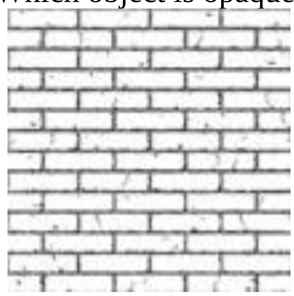
B. opaque
C. translucent
D. transparent

4.P.4A.5: Plan and conduct scientific investigations to explain how light behaves when it strikes transparent, translucent, and opaque materials.

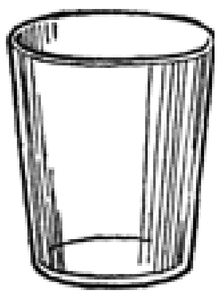
Which word describes a clear glass plate

A. opaque
B. translucent
C. transparent
D. mirrored

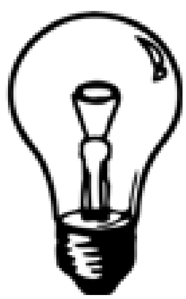
Which object is opaque?



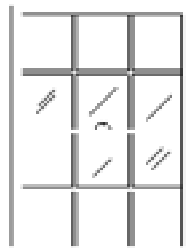
A. brick wall



B. drinking glass



C. light bulb



D. window

4.P.4B. Conceptual Understanding: Sound, as a form of energy, is produced by vibrating objects and has specific properties including pitch and volume. Sound travels through air and other materials and is used to communicate information in various forms of technology.

How will the sound of a guitar differ after having its strings made very tight?

A. The pitch of the sound will be higher.
B. The pitch of the sound will be lower.
C. The volume will be louder.
D. The volume will be softer.

4.P.4B.1: Plan and conduct scientific investigations to test how different variables affect the properties of sound (including pitch and volume).

How will the sound of a piano differ if it is played with more force?

A. The pitch will get higher.
B. The pitch will get lower
C. The volume will get louder.
D. The volume will get softer.

Madison plays the drums in the school band. Sometimes she hits the drum gently and it makes a soft sound. Sometimes, she hits the drum hard, and it makes a loud sound. What is the difference between the two kinds of sound she makes?

A. the direction
B. the pitch
C. the volume
D. the thickness
E.

If you and your friend were on the moon, you could not hear him – even when he shouted. Why would no sound reach you from your friend?

A. The moon is too small to transmit vibrations.
B. The moon is not solid and cannot transmit sound.
C. The moon's craters block the vibrations from being transmitted.
D. The moon has no air to transmit the vibrations.

4.P.4B.2: Analyze and interpret data from observations and measurements to describe how changes in vibration affects the pitch and volume of sound.

Tyrone plucks two strings of a violin. The first string makes a low pitch, but the second string makes a high pitch. What does this tell you?

A. the first string is producing faster vibrations
B. the second string is producing faster vibrations
C. the two strings are vibrating at the same speed
D. none of the above

Below is a chart of how FAST sound travels through different mediums (or solids, liquids, and gasses).

Medium	Classification	Speed of Sound (meters/ second)
Steel	Solid	5500
Sea Water	Liquid	1500
Air	Gas	400

A. sound travels at the same speed through all mediums
B. sound travels fastest through solids
C. sound travels fastest through liquids
D. sound travels fastest through gasses

Which of the following properties of sound is determined by the speed of the vibrations creating the sound?

A. pitch
B. speed
C. volume
D. wavelength

APPENDIX E

REFLECTION PROMPTS

The following are reflection prompts students will address in their design journals

Describe a time when you and your teammates did not agree on how to proceed with your project:

- What did you disagree about?
- Why did you disagree?
- How did your behavior change when they did not agree with you?
- What information did you use to solve the problem?

Describe a time when you and your teammates came up with a creative or innovative design or solution to a problem?

- What design element were you working on?
- How did you come up with the idea?
- Was it a team effort?
- How did your solution work out?

Describe a time you needed help from a classmate or a time when you offered someone help (adapted from Baytak, 2009).

- What kind of help was needed?
    - About game design?
    - About Scratch?

    - About light or sound content?
- Who did you help or who did you ask for help?
    - Why did you choose this person?
    - Or Why do you think this person chose you?
- What kind of help did they/you offer?

Broader prompts for halfway point and end of unit.

Describe a point in the game design project when you felt you were able to solve a challenging problem. How did each of the following help you overcome the challenge

- your creativity
- your problem-solving skills
- collaboration with others

Do you feel you have grown in your skills and abilities in problem-solving, creativity and collaboration? Reflect on one of these areas of growth. How have you changed in this area?

APPENDIX F

CO-MEASURE

Co-Measure

A Rubric to Assess Student Collaboration in STEAM Units

INFORMATION

Complete the fields below:

Name(s)

Date

Classroom Information

SAMPLE STEAM SCENARIO

Write a brief description of your STEAM scenario in the space below:

DIRECTIONS

The following rubrics are designed to be edited digitally or marked and annotated after printing

Dotted lines enclose editable areas in which to type comments

The ✓ icon denotes a clickable area to be selected or marked

1 PEER INTERACTIONS

Description

Within STEAM learning, students are expected to refer to the guidelines of the rubric with their peers to identify group goals and monitor progress towards completing the tasks. Group members then discuss how to divide tasks relying on one other's expertise to equitably complete the work. Students rely on their group members to check for accuracy in the process (e.g. Does the way we are approaching the task make sense?) and the content (e.g. Is the content accurate?). Students provide one another with feedback to help them gauge how they are doing or redirect tasks.

ATTRIBUTE	NEEDS WORK	ACCEPTABLE	PROFICIENT
Monitors tasks and checks for understanding with peers	Student does not rely on peers to discuss criteria, identify goals, monitor progress, and determine accuracy	Student occasionally relies on peers to discuss criteria, identify goals, monitor progress, and determine accuracy	Student consistently relies on peers to discuss criteria, identify goals, monitor progress and determine accuracy; multiple indicators are evident
Negotiates roles, and divides work to complete tasks	Student does not negotiate roles aligned with self/peer identified expertise, workload is not shared	Student negotiates roles aligned with self/peer identified expertise or attempts to share workload; only one indicator is evident	Student negotiates roles aligned with self/peer-identified expertise to complete tasks and workload is shared; both indicators are evident
Provides peer feedback, assistance and/or redirection	Student does not volunteer or respond to requests to assist in problem solving; provides little or no feedback	Student occasionally volunteers and responds to group member requests; peer feedback is sometimes evident	Student consistently volunteers and responds to group member requests; peer feedback is noted consistently

NOTES

2 POSITIVE COMMUNICATION

Description

Similar to collaboration in other contexts, positive communication is essential to efficiently work towards solutions. Students participating in STEAM learning are expected to respect one another to foster productive contributions by all members.

ATTRIBUTE	NEEDS WORK	ACCEPTABLE	PROFICIENT
Respects others' ideas and compromises	Student rejects others' ideas without an accountable reason, is unwilling to compromise	Student occasionally allows others to contribute their ideas, and sometimes compromises	Student consistently allows others to contribute their ideas; disagrees diplomatically and compromises
Uses socially appropriate language and behavior	Student uses socially inappropriate language and behaviors when interacting with peers	Student occasionally uses socially appropriate language and behaviors when interacting with peers	Student consistently uses socially appropriate language and behaviors when interacting with peers
Listens and takes turns	Student talks over group member, monopolizes conversations or does not talk at all	Student occasionally allows others to finish speaking before he/she speaks; sometimes apologizes for inappropriate interruptions	Student consistently allows others to finish speaking before he/she speaks; apologizes for inappropriate interruptions

NOTES

3 INQUIRY RICH/ MULTIPLE PATHS

Description

One of the hallmarks of STEAM teaching and learning is that students are given a scenario that has a variety of solutions requiring them to consider various lines of inquiry (or questions) that might arise during task completion. In STEAM collaborative problem solving, we would expect students to work with group members to explore and refine questions, negotiate with group members to choose appropriate materials and methods, and verify information and sources. This often includes a variety of solutions

ATTRIBUTE	NEEDS WORK	ACCEPTABLE	PROFICIENT
Develops appropriate questions and methods towards solving the problem	Student begins inquiry process without group discussion	Student suggests questions and/or methods to support process but does not refine questions and/or methods as he/she begins problem solving	Student suggests and refines questions and/or method to support inquiry towards problem solving
Verifies information and sources to support inquiry	Student does not rely on peers for information or to verify the validity of sources	Student occasionally checks in with peers to verify information and the validity of sources	Student consistently checks in with peers to verify information and the validity of sources

NOTES

4 TRANSDISCIPLINARY APPROACH

Description

A distinguishing characteristic of STEAM learning is that it foregrounds the problem to be solved versus focusing solely on the content and discipline that originated the problem. STEAM learning assumes students will be presented with problems closely related to local or relevant real-world issues. In STEAM collaborative problem solving, students should be able to discuss and then choose methods or materials that mimic what scientists, researchers, engineers, politicians etc. might do or use. Groups typically use digital and non-digital collaborative tools (e.g. Google Docs, email, whiteboards) to efficiently co-create and complete tasks.

ATTRIBUTE	NEEDS WORK	ACCEPTABLE	PROFICIENT
Discusses and approaches problem solving incorporating multiple disciplines	Student does not discuss or approach problem by considering multiple disciplines	Student occasionally discusses and approaches problem demonstrating use of multiple disciplines	Student consistently discusses and approaches problem demonstrating use of multiple disciplines
Shares connections to research or relevant knowledge	Student does not share connections to research or relevant knowledge	Student occasionally shares connections to research or relevant knowledge, which might include events, places, resources or previous experience	Student consistently shares connections to relevant knowledge including events, places, resources or previous experience
Negotiates relevant method or materials to solving the problem posed	Student does not negotiate methods or materials, or chooses methods and materials irrelevant to problem posed	Student occasionally negotiates methods or materials, and chooses relevant methods and materials to problem posed	Student consistently negotiates methods or materials, and chooses relevant methods and materials to problem posed
Uses tools collaboratively to approach task	Student uses tools (digital or non-digital) individually	Student occasionally uses tools (digital or non-digital) collaboratively to approach task	Student consistently uses tools (digital or non-digital) collaboratively to approach task

NOTES

APPENDIX G

FOCUS GROUP PROTOCOL

Good morning, thank you for agreeing to participate in this focus group discussion. Your thoughts and ideas will help me to understand how you felt about the game design unit and its impact on your creativity, collaboration and problem-solving skills.

Problem Solving:

- How did your group handle problems that arose while working on your game design?
- Do you feel like everyone had a voice in the process?
  - Can you give me some examples of how you made sure everyone had a voice?
  - What did you do to make sure that all ideas got heard and considered?
- How did you decide on your solutions?

Creativity:

- Can you share an example of how you felt like you were able to be creative with your game design?
- Tell me about something you created that you are proud of.
- Do you think it is good to be creative in science/STEAM? Why or why not?

Collaboration and Teamwork:

- Why is collaboration important in science?

- Can you tell me about a time when collaboration with your group was hard?
    - How did you resolve the issues?
- Do you feel like participating in collaborative activities in STEAM is important?
    - Can you tell me about a time collaboration worked for your group?
    - What did you learn?
    - How did it affect the final project?

Is there anything else you would like for me to know about your project work?