The Effects of Digital Game-Based Instruction on Knowledge Acquisition and Retention of Genetics Content

Brinley Kantorski

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THE EFFECTS OF DIGITAL GAME-BASED INSTRUCTION ON KNOWLEDGE ACQUISITION AND RETENTION OF GENETICS CONTENT

A Dissertation
Submitted to the School of Education

Duquesne University

In partial fulfillment of the requirements for the degree of Doctor of Education

By
Brinley Kantorski

August 2022
THE EFFECTS OF DIGITAL GAME-BASED INSTRUCTION ON KNOWLEDGE ACQUISITION AND RETENTION OF GENETICS CONTENT

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ABSTRACT

THE EFFECTS OF DIGITAL GAME-BASED INSTRUCTION ON KNOWLEDGE ACQUISITION AND RETENTION OF GENETICS CONTENT

By

Brinley Kantorski

August 2022

Dissertation supervised by Jeff Miller, Ph.D., John Pollock, Ph.D., & Karen Levitt, Ph.D.

Digital educational games have been a part of the educational landscape since the early 1970s. Since then, there has been a proliferation in the quantity, format, type, and quality of digital educational games available to classroom teachers. Despite this, the body of literature surrounding the effectiveness of these digital educational games remains highly fragmented and lacks unifying themes. While some literature exists to support the use of digital educational games in immediate knowledge acquisition, little research has been done on how digital educational games impact the retention of knowledge in the long term. As such, this study examines how the use of a digital educational game impacts both immediate knowledge acquisition and the retention of that knowledge long-term. Outcomes of a digital educational game are compared to outcomes of hands-on instruction in the context of genetics content delivered in a high school biology course. Secondary analysis of an existing data set serves to
determine if a digital educational game provides increased knowledge acquisition immediately after instruction when compared to hands-on instructional activities. Additionally, the investigation determines if a digital educational game provides increased knowledge retention thirty days post instruction when compared to hands-on instructional activities. The examination and analysis of the data, which includes pre-test, immediate post-test, and long-term post-test assessment scores was be conducted. The findings from this study help to advance the understanding of the value of digital educational games and their appropriate implementation in science classrooms.

*Keywords:* game-based learning, educational gaming, digital educational games, gaming effectiveness, knowledge acquisition, knowledge retention, genetics instruction
DEDICATION

This work is dedicated to my mother, whose constant support, encouragement, and advice has granted me the persistence to succeed.
ACKNOWLEDGEMENT

I would like to extend my deepest gratitude to my committee members, Dr. Jeffrey Miller, Dr. John Pollock, and Dr. Karen Levitt. Your expertise, guidance, and encouragement gave me the invaluable tools to get through this process.

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To my husband, there aren’t sufficient words to express the thanks for every cup of coffee brewed, every postponed plan rescheduled, and every Kleenex fetched. Thank you for your love and support.

To Mom and Joe, I couldn’t have done it without you. Thank you for believing in me.
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Chapter I

Introduction

Though games have been used as teaching tools for millennia, a unified definition of what does or does not constitute a game still remains elusive (Juul, 2003; Salen & Zimmerman, 2004). Despite this, both non-digital and digital programs alike have claimed the “game” moniker and have been integrated into the modern schooling system at the elementary, secondary, post-secondary, and graduate levels in the hope that their usage would support student learning (Holmes & Gee, 2016; Wilson, 2016). Over the past several decades, the field of education has seen exponential growth in the number of digital educational games (DEG) available to complement classroom instruction (Adams & Ault, 2009; De Frietas, 2006; Egenfeldt et al., 2008; Gee, 2005; Wilkinson, 2016). These digital educational games exist across a wide range of quality and complexity, yet evidence of their effectiveness at supporting students’ retention of knowledge remains mixed (Akl et al., 2010; Annetta et al., 2009; Bays & Hermann, 1997; Blakely et al., 2009; Boeker et al., 2013; Boet et al., 2013; Brom et al., 2011; Coller & Scott, 2009; Cowen & Tesh, 2002; De Frietas, 2006, 2018; Henry, 1997; Kanthan & Senger, 2011; Ricci et al., 1996; Rondon et al., 2013; Schuh et al., 2008; Tsai et al., 2012; Wilson et al., 2018; Wong et al., 2007). Although the prevalence of these games in the elementary and secondary level classrooms is increasing, the literature supporting the effect of these games on these students’ abilities to learn and retain information in these settings is limited (De Freitas, 2018; Gee, 2005, Papastergiou, 2009; Wilkinson, 2016).

The National Research Council’s (NRC) *National Science Education Standards* call for the use of instructional strategies that support science inquiry in the classroom, a challenge that game-based instruction seems uniquely poised to tackle (National Academy Press, 2000). It is
important and necessary to investigate the effectiveness of game-based instruction with DEGs in comparison to other instructional strategies that also support the principles of science inquiry, such as hands-on instruction, to determine if one strategy is more effective than another. Digital educational games seem set to fulfill both Ausubel’s (2000) and Gagne’s (1988) conditions for learning in a virtual environment which include: contextualization, information chunking, skill review, cueing, and skill practice, all of which, set the stage for successful acquisition and retention of both declarative and procedural knowledge. Furthermore, the literature on the role of DEGs in the improvement of students’ long-term content retention is mixed and limited. With the increased number of DEGs available to educators, additional efforts to evaluate their effectiveness are needed.

**Problem Statement and Significance**

Students’ retention and recall of both declarative and procedural knowledge on standardized tests is a major component of modern schooling (Morgan, 2016). During standardized testing, students are asked to demonstrate their knowledge of content that they may have learned many months prior and may only have had limited review or re-teaching prior to testing. As such, if there is a teaching methodology that allows for more effective learning, with students being able to recall and apply knowledge for longer periods of time, this would be valuable information for both educators and students alike. By identifying such a methodology, teachers could implement it in their classrooms to help ease the burden of re-teaching placed upon teachers leading up to standardized testing. When knowledge is more effectively retained after its initial teaching, it can decrease or eliminate the need for re-teaching later. Reducing the amount of re-teaching or review of a topic allows teachers to focus their efforts in other areas in preparation for standardized testing or and allows them to devote instructional time to content
that needs more attention. Long-term retention is critical for knowledge transfer to applied settings after schooling.

The Current Study

Although there are a multitude of DEGs available to educators, for this study it was important to identify a DEG that specifically met the following criteria: has high quality production value (e.g. graphics, audio, interactivity), includes accurate educational content related to the concepts of sexual reproduction, patterns of inheritance, and predicting the phenotypes and genotypes of genetic crosses, and is readily available and easily accessible to teachers and students. After conducting online searches and reviewing several candidate games, Pigeonetics emerged as the best DEG candidate for further research.

Therefore, this study will investigate the game, Pigeonetics, and its impact on the acquisition and retention of genetics content knowledge. Pigeonetics is a DEG created by the University of Utah’s Genetic Science Learning Center (Genetic Science Learning Center, 2015). This free, single-player, web-based game is promoted as an exemplar of a quality DEG. The game features: modern visuals, player interactivity, high-quality music and sound effects, engaging challenges to be solved by the player, and accurate educational content. The game uses a theme of pigeon breeding to teach the genetics concepts of sexual reproduction, patterns of inheritance, and predicting the phenotypes and genotypes of genetic crosses. Together, these game features and educational content, make Pigeonetics a prime candidate for the current study.

Study Parameters

The study utilizes an existing data set, sourced from a quasi-experimental study conducted by Duquesne University faculty member, Dr. John A. Pollock. The study was conducted at Moon Area High School in Moon Township, PA, a suburban community located in
the Greater Pittsburgh metropolitan area from February 2019 to April 2019. This data set was the result of a study that examined the effectiveness of using games as teaching tools in a science classroom. The study design followed the methodology put forth by Ricci, Salas, and Cannon-Bowers’ in their 1996 paper, “Do Computer-Based Games Facilitate Knowledge Acquisition and Retention?” This methodology follows a pre-test, immediate post-test, and long-term post-test model. Figure 1 below shows the research activities of the original study which generated the data set being used.

**Figure 1**

*Quasi-experimental study design*

![Quasi-experimental study design diagram]

*Note.* Study design showing, pre-test, control and experimental groups, immediate post-test, and long-term post-test activities which generated the data set being used.

Participants in the study were high school students enrolled in an academic Biology course as part of their 9th grade science curriculum. Student participants ranged in age from 14-16 years old. The data set was gathered using two survey instruments, *Genetics Content Knowledge Test #1* and *Genetics Content Knowledge Test #2*. These instruments were constructed from previously validated genetics content tests and used to collect the following pieces of information from participants: participants’ name (for data matching purposes), gender, and responses to nine multiple choice questions pertaining to Genetics content. *Genetics Content*
Knowledge Test #1 was used as a pre-test for the study, as well as the long-term post-test.

Genetics Content Knowledge Test #2 was used as the immediate post-test assessment. After participant responses had been collected, the resulting data was coded and entered into SPSS software. This data set has not previously been analyzed.

**Research Questions**

The study explores the use of game-based learning using the DEG, Pigeonetics, and its impacts on the acquisition and retention of Genetics content knowledge for 9th grade, biology, public school students by investigating the following research questions:

1. Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands-on instruction for genetics declarative knowledge?
2. Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands-on instruction for genetics procedural knowledge?
3. Does game-based instruction using Pigeonetics result in greater long-term retention than hands-on instruction for genetics declarative knowledge?
4. Does game-based instruction using Pigeonetics result in greater long-term retention than hands-on instruction for genetics procedural knowledge?

**Conclusion**

With increasing demands being placed on students to recall vast amounts of information on standardized tests, instructional methodologies and tools that result in longer content knowledge retention times are valuable components for educators to implement in their classrooms. Despite DEG presence in classrooms across the globe, there is limited scholarly study of their impact on student content knowledge retention rates. The goal of this study is to
investigate if the use of DEG provide improved acquisition and retention rates of content knowledge over more commonly used hands-on instructional practices.
Chapter II

Literature Review

A Brief History of Educational Gaming

Games in their many forms and iterations have been used as teaching tools for millennia. As far back as 3100 BCE, games were being used to teach the players various skills. Senet, an Egyptian board game, used stone pawns moved among squares marked with hieroglyphics to teach logic and reasoning skills (Finkle, 2008). In Ancient China, Wei-qi, a game used to teach land capture techniques and conquest, was first played around 400 BCE (Fairbairn, 1995). Archeological evidence dated to approximately 600 AD, shows the that precursors to modern mancala games were being used to model counting, mathematics, and logic skills in Ethiopia (Parkhurst, 2005). Another early educational game was the Indian military strategy game, Chaturanga, first developed in the 7th century. (Wilkinson, 2016). Chess was used to teach military strategy and resource management in Europe during the Middle Ages (Wilkinson, 2016). Leaping forward to the early 1900s, games continued to be a tool for learning. A game titled, The Landlords Game, dated 1902, was a precursor to Parker Brothers famous Monopoly game. The game strove to teach its players about the factors and influences in capitalist societies (Wilkinson, 2016). Military strategies and tactics remained a common thread throughout educational gaming. After World War II, the American military began implementing various simulations as part of their training. With titles such as, “Air Defense Simulation” and “CAR-MONETTE-Combined Arms Computer Model” the army taught personnel about enemy target identification and radio communication skills (Wilkinson, 2016), albeit with what would be considered very rudimentary technology today. The 1950s marked the beginning of “the modern era of simulation gaming” as commercial and corporate entities began to integrate games
into educational practice. Governmental organizations were also beginning to integrate gaming into their training and educational practices by the early 1960s (Duke, 1964). For example, “Metropolis” was a simulation style game developed in 1964 that was used to educate city officials in Lansing Michigan on budgeting and city planning (Duke, 2011).

With advances in technology and the birth of the commercial video game industry, digital educational video games make their first appearance in the classroom. “Lemonade Stand,” a text-based simulation game which models basic economics and business practices, was being used in classrooms as early as 1973. Following closely in 1974, one of the most famous digital educational games of all time, “Oregon Trail” appeared in the classroom (Wilkinson, 2016). The 1980s and 90s saw increasing diversification in both the number of games available and the subject matter covered by games: “Where in the World is Carmen Sandiego” (first developed in 1985) for geography and social studies, “Math Blaster” (first developed in 1983) and “Number Muncher”, first released in 1986, for mathematics, “Evolution: The Game of Intelligent Life” (first released in 1997) and “The Incredible Machine” (first released in 1993) for the sciences, “Civilization” for History” (first released in 1991), and “Verb Viper” (first released in 1982), and “Reader Rabbit” (first released in 1983) for English and Language Arts (Adams, 2009). While not an exhaustive list, it is clear to see that the range of digital educational games available to classroom educators exploded in the last two decades of the 20th century.

As access to the internet via broadband connections increased in the mid-2000s, so did the way in which many digital educational games were accessed. Broadband internet was able to support media-rich content like streaming video and Flash based animations and games (Jurgenson, 2012). Websites such as BrainPop.com, PBSkids.org, Jumpstart.com, and ABCmouse.com arose to host in-browser, digital educational games. These sites provided a safe
online space for children to learn and practice new skills. The release of Apple’s iPad in 2010 changed the landscape of digital educational gaming. With the development of tablet computers came the ability for even more customization in game topics and content. Now game creation and development could be handled by individuals with even basic computer programming knowledge. Applications, commonly abbreviated to simply “apps,” were able to be produced by almost anyone and submitted for easy distribution on their respective system’s app store. Advancements in technology, namely the ease with which individuals or small companies could develop and release apps, allowed for the creation of many digital educational games. With the exponential growth and diversification of digital educational games over the last half century, questions arise as to their effectiveness as educational tools.

A definitive answer to whether or not games are effective teaching tools and why they may or may not be, is not clear. In fact, simply defining what constitutes a game varies widely across the literature. Herein lies one of the main issues surrounding the field: what exactly is a game? There are no hard and fast rules as to what can be considered a game. No definitive list of features or components that a game must possess exists. Attempts have been made to quantify the features or components of successful games, however these have not been widely adopted, even though games have been used as teaching tools for many years (Egenfeldt et al, 2008; Gee, 2005; Wilkinson, 2016). One of the first modern definitions of a game was outlined in *Rules of Play*, by theorists Salen and Zimmerman (2004), “A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.” Expanding upon Salen and Zimmerman’s definition, Juul, another game theorist, put forth this expanded definition, “A game is a rule-based formal system with a variable and quantifiable outcome, where different outcomes are assigned different values, the player exerts effort in order to
influence the outcome, the player feels attached to the outcome, and the consequences of the activity are optional and negotiable.” (Juul, 2003). While obviously more verbose, Juul’s definition lays out additional components that help to better distinguish games from activities such as free-form and unstructured play, hypertext fiction, storytelling, and non-interactive multimedia. Figure 1 provides examples of activities that fall into the categories of “Not Games” “Borderline Cases” and “Games” to further illustrate Juul’s definition of a game.

**Figure 2**

*Juul’s Model of Games with Examples*

Even with Juul’s enumerated components for games, the required components are always executed differently. For instance, the required components for an entertainment game would look and function differently than the required components of a “serious” or educational game. In entertainment gaming, oftentimes more focus is placed on emotional investment in the setting and characters, as well as the effort required to achieve a successful outcome. These components, coupled with a focus on the variability of outcomes as well as the valorization of the winning outcome, tend to be more often present in entertainment games. Educational games tend to focus on the fixed rule component of games, which is used to model the rules of the system or content the game is designed to teach. Still more differences exist even among purely educational games; components for a game meant to teach content-based knowledge are likely to look quite different than those components needed in a game designed to teach procedural knowledge or skills. Moreover, different disciplines also define games differently and, as of yet, the field of education has not settled on a concrete definition. As such, what one researcher might consider a game might differ greatly from those of their colleagues. This phenomenon can lead to confusion and fragmentation in the literature. A 2016 article by Holmes and Gee specifically reference this lack of consensus in terminology as a major contribution to the confusion surrounding game-based instruction, “As these changes in terminology suggest, the diversity of instructional strategies and technologies associated with games make it difficult to identify GBTL (game-based teaching and learning) as a unitary educational practice.” (Holmes & Gee, 2016). The article goes on to state that there are both educators and researchers scattered across varied disciplines who, due to this lack of shared terminology, work in relative isolation and whose work fails to gain traction a result (Holmes & Gee, 2016). For example, are simulations used to teach medical procedural knowledge, games? What about word puzzles or riddles? Interactive
diagrams? Jeopardy-style quiz shows? All of these examples have at one time or another, been referred to as games in the educational literature (Bays, 1997; Cowen, 2002; Henry, 1997; Schuh, 2008).

Digital educational games have increased in prevalence over the past few decades due in part to advances made in technology and the availability of computing devices in schools (De Frietas, 2006). In the past, educators were limited to non-digital based games such as “win-lose-or-draw,” math “baseball,” or verbal quiz style games that did not require any technology to play. With these advances has come an increase in the types of games available to educators. Today, educators have access to a wide variety of game types and formats including action/adventure, simulation, online, multiplayer etc. These game types require technology to play; however, they are increasingly accessible to educators in the US.

**Current Standards and Recommendations in Science Education Instructional Practice**

The wide range of topics that constitute a student’s science education call for a variety of instructional practices. The National Research Council’s (NRC) *National Science Education Standards* set forth an overarching vision and guidance for science education in the United States. Within these standards are suggestions for best practices and classroom instructional strategies. Specifically highlighted in the standards is inquiry-based learning (NGSS, 2013). Inquiry-based learning has a multi-faceted definition that includes learning activities such as making observations and posing questions, examining existing information, interpreting data, constructing answers, explanation, and predictions, and communication of results. It is important to note, however, that the NRC does not recommend a single instructional strategy for implementing science inquiry in the classroom (National Academies Press, 2000). Instead, NRC
suggests using a variety of instructional strategies that support inquiry-based learning (NGSS, 2013).

One of the oldest and most utilized instructional strategies is didactic lecture. Though its use is prevalent across disciplines, its effectiveness in supporting inquiry-based learning is debatable at best (Keegan, 1993; Lord, 2006; Raman, 2015; Richardson, 2008; Shreeve, 2008). In these cases, the argument is made that didactic lecture on its own can impart information to its audience; however, supplementing or pairing didactic lecture with other instructional strategies is more effective. Didactic lecture on its own struggles to integrate the principles of science inquiry. Despite this, didactic lecture is often seen as the default instructional methodology used in many science classrooms. As such, it is often used as the control condition for comparative studies of instructional strategies. (Ashcraft, 2006; Dunnington et al., 1987; Raman, 2015; Reeves, 2001; Schlenker, 1970; Taylor, 1959) In these cases, the achievement scores of students who received instruction via didactic lecture are compared the achievement scores of students who received instruction via other instructional strategies. Mirroring the findings of Keegan, Lord, Richardson, Shreeve, and Raman, these studies found that students who received instruction via didactic lecture had lower achievement scores than those who received instruction via other instructional strategies such as game-based learning. One might expect that students who received game-based instruction would have higher achievement scores than those who received didactic lecture, but this is not always the case. In fact, many studies show that there is little to no difference in students' immediate knowledge acquisition between lecture-based and game-based instruction (Akl, 2010; Annetta, 2009; Bays, 1997; Blakely, 2008; Brom, 2011; De Frietas, 2006; Papastergiou, 2009; Ricci, 1996; Wilson, 2018; Wong, 2007).
Another commonly used instructional strategy is hands-on learning. Hands-on learning can be implemented across disciplines. When used in the sciences, it is often implemented in laboratory procedures. Hands-on instruction can integrate with the principles of science inquiry as it can be structured to model the scientific method that includes asking questions, making observations, constructing hypotheses and predictions, followed by testing to collect data and analyzing data, to draw conclusions. This empirical approach, originally codified about 400 years ago by René Descartes, Francis Bacon, and Isaac Newton, is the central tenet of scientific discovery (National Academies Press, 2000). However, it should be noted that just because a classroom activity is hands-on, does not necessarily mean that the activity is inquiry-based. In order to be considered inquiry based, the hands-on activity must engage students with opportunities for investigating, evaluating, discussing, and creating. Based on previous research which compared the effectiveness of didactic lecture to game-based instruction, one could expect that additional literature could be found that explored the effectiveness of hands-on learning with that of game-based instruction. However, research on this topic has yet to appear in the academic literature. As such, this is an area prime for research; how does the effectiveness of hands-on learning compare with that of game-based learning?

Game-based learning is another instructional strategy that can be employed across disciplines, including science. The game format as well as the type i.e., quiz style, simulation, action/adventure, etc. can vary widely and yet still find their place in classroom instruction. In fact, game-based instruction also lends itself well to integration with science inquiry principles. Games, especially digital games, can allow students the opportunity to carry out many of the same steps found in the scientific method in a safe and low-risk setting. This low-risk setting allows students to be inquisitive, experiment, and play in an environment where failure is not
physically or academically risky. Student anxieties over “getting the right answer” or “doing it right” are lessened since in a digital game setting, the student can simply restart or try again without penalty. Again, the ability to change variables, test outcomes, and make predictions within the virtual game environment all help to facilitate the skills needed for science inquiry.

**Digital Educational Games Across Content Disciplines**

The current body of literature surrounding educational games is fragmented, with studies of educational games varying greatly across disciplines (De Freitas, 2018). Digital educational games can be found in most disciplines, however, as with terminology, a lack of standardization contributes to the fragmentation of the field. Almost all disciplines integrate educational gaming in some capacity, including Science, Math, Language Arts, Social Studies, Health and Physical Education, Computer Science, Engineering, and Medicine. These all have bodies of published literature on the use of digital educational games in their respective fields. What each discipline considers a game varies, and the ways these digital education games are integrated into their curriculum vary as well. Differences exist in their definitions of a successful or effective game; some fields focus more strongly on improved test scores, others increased student motivation, still others on the demonstration of a specific set of motor skills. The prevalence of digital educational games also varies widely between disciplines. Science and math topics are seen quite often in digital educational games, alongside medical procedure topics, which have a more extensive body of literature. Digital educational games are seen less frequently in Language Arts and Social Studies; however, smaller bodies of literature exist for these disciplines as well. Additionally, no standardization for research methodologies exists between or even within disciplines. Differing definitions of effectiveness, acquisition, retention, short term, and long
term are seen, again, both within and between disciplines. As such, this phenomenon makes drawing clear trends across studies problematic.

**Digital Educational Game Types Studied**

The early days of digital educational gaming saw the creation of basic quiz-style games, which present users with content-based questions, usually in multiple choice format, where users must select the correct answer to progress through the game. This game format, while novel for its time, is a simple digitization of traditional assessments- choosing an answer from an existing pool to respond to a question. The technology to create these types of games was relatively simple and therefore, one of the first to be implemented in digital educational gaming. This quiz-style game format was able to be applied to almost any content topic and, as such, it became one of the most studied game formats of digital educational gaming (Blakely, 2009; Cowen & Tesh, 2002; Kanthlan, 2011; Ricci, 1996; Rondon, 2013; Schuh, 2008).

In addition to quiz-style games, simulation style games also represent a significant portion of the existing literature, especially in science and medical fields (Akl, 2010; Bays, 2007; Blakely, 2009; Boeker, 2013; Boet, 2013; Cowen, 2002; Henry, 1997; Kathan, 2011; Rodon, 2013; Schuh, 2008; Wong, 2007). Simulation games are more complex than quiz-styles games, due in part to their ability to demonstrate and model complex biological and physical processes. Most relevant to this study are studies that examine the effectiveness of games designed for use in a high school biology course. These studies help to shed light on the types of games currently being implemented in classroom practice as well as their effectiveness. Brom’s 2011 study of the use of a digital educational game to teach concepts of animal behavior within the context of a high school Biology course found that students who played a digital educational game as supplement to lecture had comparable achievement scores on content knowledge tests.
administered immediately after instruction, to those students whose lecture was supplemented with videos. Interestingly, when a second knowledge test was administered one month after instruction, the achievement scores of students who played a digital educational game were higher than those students who viewed videos (Brom, 2011).

Most relevant to this study are the works of Annetta (2009) and Wilson (2018), who both studied digital educational games used to teach Genetics concepts. Annetta’s (2009) study compared the achievement scores of students who played a digital educational game as a review activity for the Genetics portion of their biology course curriculum with those of student who completed paper and pencil practice worksheets and class discussion as a review activity. Findings from this study showed no difference in the achievement scores between the student groups. Wilson’s 2018 study compared the Genetics content knowledge gains of students who received game-based instruction from the DEG, *Geniverse*, versus students who received instruction via non-game-based instruction. Results of the study showed that no significant differences existed between the achievement scores of both groups (Wilson, 2018).

**Study Population Age Groups in Digital Educational Gaming Research**

Despite the availability of digital educational games across a wide range of grade levels and target audiences, much of the existing literature reports on the impact of digital educational gaming in post-secondary settings. Notably, digital educational games that focus on medical knowledge and procedures seem to be one of the most studied type of educational games. Therefore, most of the participants in these studies are undergraduate, graduate, or adult learners (Blakely, 2009; Boeker, 2013; Boet, 2013; Coller & Scott, 2009; Cowen & Tesh, 2002; Dunnington et al., 1987; Goldberg, 2000; Henry, 1997; Kanthan, 2011; Ricci, 1996; Rondon, 2013; Schuh, 2008; Wong, 2007). This is because the content contained in these games is not
part of a traditional curriculum until a student’s collegiate or professional education. There is considerably less published research available that examines the effectiveness of games in elementary, middle, or high school settings (Annetta, 2009; Brom, 2011; Papastergiou, 2009; Tsai, 2012; Wilson, 2018). This discrepancy may be due to sample convenience; many researchers studying digital educational games are also professors who have ready access to undergraduate or graduate students. Additionally, because most undergraduate and graduate students are over the age of 18, they can consent to participate in research. To conduct a study with participants who are under the age of 18, as most K-12 are, both parental consent and student assent is required for study participation. These additional requirements can pose challenges to participant recruitment and study design and may dissuade researchers from targeting student populations under 18 years of age for inclusion in research studies.

**Knowledge Acquisition, Retention, and Learning**

In today’s educational system, particularly in the United States, there is a focus on students being able to learn targeted content and then demonstrate their learning on a standardized test (Morgan, 2016). Oftentimes, a school’s funding is tied to the students’ results on these standardized tests and as such, has resulted in a trend of teachers “teaching to the test.” This phenomenon of teaching to the test places an emphasis on acquiring the target knowledge, and retaining it until the standardized testing occurs, with little to no focus on any retention of knowledge past that point.

Two of the major classifications of knowledge are declarative and procedural (Gagné, 1988). Declarative knowledge is also commonly referred to as factual knowledge. For example, knowing that the Emancipation Proclamation was issued on January 1st, 1863, or that the byproducts of cellular respiration are carbon dioxide and water, are both pieces of declarative knowledge.
knowledge. Alternatively, procedural knowledge refers to the cognitive skills involved in knowing the sequence of steps in a process and how to execute them. Knowing how to multiply two binomials in a mathematic equation, or how to locate a book in a library’s collection, are both examples of procedural knowledge. Like many educational disciplines, in Biology, the topic of genetics involves both declarative and procedural knowledge.

Learning and Knowledge Acquisition

Gagné’s work has helped to identify specific conditions necessary for learning of both declarative and procedural knowledge. These conditions, when paired with clear and appropriate learning objectives, set the stage for meaningful learning to occur (Gagné, 1988). Specifically, Gagné is reflected in components of Ausubel’s work (2000), stating that declarative knowledge must be explicitly linked to students’ prior knowledge base. Connections between prior knowledge and the new declarative knowledge need to be drawn for learning to occur. The contextualization of the declarative knowledge in a larger framework is also stressed. Furthermore, declarative knowledge is served by the process of “chunking” or breaking up the information into smaller, distinct chunks when being presented (Gagné, 1988). For procedural knowledge, Gagné’s conditions for learning include a review of previously learned skills that are necessary for the new procedural knowledge, the cueing of each individual component step of the procedural knowledge, and opportunities for repeated practice (Gagné, 1988). The complexity of genetics content requires that students be able to learn both declarative knowledge and procedural knowledge to have a deep and meaningful understanding of the topic. As such, teaching methodologies and tools that support the specific conditions outlined for both declarative and procedural knowledge are of interest. Digital educational games provide the necessary conditions for learning to occur.
Long Term Content Retention

At the most basic level, knowledge retention refers to the ability of a learner to recall information that has been learned previously. That is to say that in order for information to be retained, it had to be acquired through learning first (Kihlstrom et al., 2007). Human memory is divided into two distinct forms: implicit memory and explicit memory (Squire, 2004). Implicit memory is characterized by being used to complete tasks unconsciously; for example, remembering how to tie your shoes, how to ride a bike, or how to do a push-up (Curran & Schacter, 2013; Sherry & Schacter, 1987). Implicit memory deals with procedural knowledge, like how to complete various tasks. Explicit memory, however, is characterized as being used to remember factual information in a conscious and deliberate act (Squire, 2004). For example, knowing that the formula for calculating the area of a circle is $A = \pi r^2$, that Botswana is a landlocked country in Africa, or that ribosomes manufacture proteins in the cytoplasm of cells all utilize explicit memory. Explicit memory deals with being able to recall declarative knowledge.

In the American education system, students are most often tasked with utilizing their explicit memory skills to remember information and to demonstrate their knowledge. Most assessments that a student encounters during their coursework will involve explicit memory; students must consciously think about a query and provide the desired piece of declarative knowledge. This skill is taxed most strenuously when students participate in standardized testing. Standardized tests require students to recall and demonstrate knowledge that may have been learned many weeks or months previous by accessing their explicit memory. As such, it is important to investigate if specific instructional practices or educational tools can better support explicit memory learning as well as if these practices and tools can improve the retention of this knowledge.
Pigeonetics: a digital educational game about Genetics

Pigeonetics is a digital educational game produced by the University of Utah’s Genetic Science Learning Center (Genetic Science Learning Center, 2015). The single-player, online game is available both as an in-browser game as well as an iPad app; both of which are free to play. The game contains all of the expected components of a modern digital educational game: visuals, interactivity, music and sound effects, a challenge to be solved by the player, and educational content. Additionally, Pigeonetics provides accessibility options for deaf or hard of hearing players, with the inclusion of closed captioning. The game was designed to teach genetics concepts related to sexual reproduction, patterns of inheritance, and predicting the phenotypes and genotypes of genetic crosses. The game opens with an overview that discusses the rationale behind the setting and theme of the game, that of pigeon breeding. This overview sets the stage for gameplay and provides context for the goals contained within the game. After the introduction, a tutorial introduces the player to the mechanics of the game which include how to choose pigeons to be used in a genetic cross, how to manipulate those pigeons’ chromosomes and allele combinations and how to hatch a new pigeon from an egg. From this tutorial, players are presented with the first level of the game, with a very simple goal. Using the information from the introduction and tutorial, the player then attempts to breed a pigeon with the goal characteristics. If the player is successful in breeding a pigeon with the goal characteristics, they are presented with a win screen which displays their pigeon as well as supplementary information about the specific content used in that level. For example, in level three of Pigeonetics, the player is asked to breed a male, crested pigeon. On the win screen immediately following, level three players are presented with a text prompt that reiterates the main idea of the level, “Sex and crest are inherited separately,” as well as an “Explain” button that provides even
more in-depth and detailed information about the concepts covered in the level. Figures 3 and 4 below show the win screen and the in-depth information available to players after completing level three of *Pigeonetics*.

**Figure 3**

*Pigeonetics Level 3 Win Screen*

![Pigeonetics Level 3 Win Screen](image)

*Note.* After a player successfully completes a level, they are presented with a text prompt reiterating the main idea of the level.

Gameplay continues with additional levels and increasing difficulty. In levels where new concepts are needed to solve the goal, information is presented immediately prior to that level. Levels increase in difficulty as the game progresses because the genetics concepts and content introduced in the levels increase in complexity. Just as teachers would introduce simple genetics
concepts such as chromosomes, sexual reproduction, and alleles early in a unit, *Pigeonetics* follows a similar path. Following these topics are topics such as dominant versus recessive alleles and multi-allele genes. Finally, complex topics such as sex-linked characteristics, partial or incomplete dominance, and epistatic inheritance patterns appear only in the final levels of the game.

**Figure 4**

*Pigeonetics Level 3 Explain Screen*

![Image of explain screen](image)

*Note.* After clicking the “Explain” button, additional in-depth information related to the concepts covered in the completed level are presented.

Players are presented with a score, which is represented by a number of golden eggs shown on the win screen following a level. Players can receive one, two, or three golden eggs depending on their performance in the level. Completing a level in the fewest amount of breeding rounds required nets a player three golden eggs, while more numerous attempts reduce
the number of golden eggs rewarded. Figure 3 shows the successful completion of level three, at the highest level of performance, which has earned the player a score of three golden eggs.

When players have successfully completed all 26 levels of Pigeonetics, they are presented with a final win screen, congratulating them on their success. From this screen, players are provided with the opportunity to replay any of the previous levels to attempt a higher score. Figure 5 shows this final win screen.

**Figure 5**

*Pigeonetics Final Win Screen*

> Congratulations!

> You completed all the puzzles!

> Select the pause menu to replay for a better score.

*Note.* From this final win screen players can access all previous levels and attempt to improve their scores.

**Conditions for Learning in Pigeonetics**

Digital educational games are uniquely situated to fulfill Gagné’s conditions for learning. *Pigeonetics*, a digital educational game about the Genetics concepts of sexual reproduction, chromosomal inheritance, and trait expression, provides conditions that set the stage for learning
to occur. Gagné’s first condition required for learning is a connection to prior learning. When a user starts *Pigeonetics*, before gameplay begins, a short review of Genetics concepts is presented. This review sets the stage for what the game will be about (e.g. pigeon breeding) and how it is connected to previously learned Genetics concepts like biological sex and sexual reproduction. Additionally, the review provides context to the game explaining why pigeons are bred for specific traits and how the resulting offspring are used in society. Figure 6 shows a screenshot of part of the review portion of *Pigeonetics*. In this example, the prior knowledge being referenced is “Sex is determined by chromosomes. In people, they’re X and Y.” This knowledge is being connected to new knowledge which is required to play the game with the statement, “In pigeons, they’re Z and W.” This explicit connection between prior knowledge and new knowledge helps to foster an environment that is conducive to learning.
Review of Prior Knowledge in Pigeonetics Gameplay

Note. A screenshot from Pigeonetics review portion showing the connection between prior knowledge and the new knowledge required to play the game.

Gagné’s second condition, the breaking of knowledge into smaller pieces and presenting these pieces one at a time, a strategy known commonly as “chunking”, is also present in Pigeonetics. The process of predicting the results of genetic cross is a process that requires several steps. Pigeonetics presents each step in the process as an individual level with a goal to be achieved by the player. For example, the very first level of in the Pigeonetics game is to set up a genetic cross that would result in a female pigeon. Figure 7 shows this first step in solving the genetic cross.
Note. Level 1 of *Pigeonetics* asks the user to select the parental pigeons to be used in a genetic cross with the ultimate goal of producing a female pigeon offspring.

As the level progresses, the subsequent steps required to set-up, complete, and interpret the genetic cross are also presented, one at a time. As such, not only are the individual goals of *Pigeonetics* separated into distinct levels with increasing difficulty, but the individual steps required to set-up, solve, and interpret a genetic cross are chunked within each level.

Another condition required for learning procedural knowledge, set forth by Gagné, is a review of prior skills. Before a student can learn a new skill, the skills required to complete a new skill must be reviewed. Much like how the connections to prior declarative knowledge are
covered in the review portion at the beginning of the game, the procedural skills needed to complete the goals in the game are reviewed before new procedural skills are introduced. For example, in level 4 of *Pigeonetics*, the user is asked to create a cross that would result in a male pigeon with a feathered crest. This goal requires users to have mastered two prior procedural skills: creating a cross that results in a male pigeon, and understanding how allele dominance impacts inherited characteristics. Prior to level 4, the player had been asked to create a cross the results in a male pigeon, and also was provided with a review of dominant and recessive alleles. The combination of using simple goals early in the game to teach skills that are required to complete later goals, provides students with opportunities to review and practice these prior skills. Figure 8 shows a screenshot from *Pigeonetics* that appears when users have successfully completed level 4 of the game. Note that on this win screen, the main idea of the level is reinforced and stated in simple terms, “The crest allele is recessive to the ‘no crest’ allele.” This helps to reinforce the skills practiced in level 4.
Reinforcement and Opportunities for Practice in Pigeonetics

Note. The screen that appears after users successfully complete the goal of level 4, creating a cross that results in a male, crested pigeon. The main idea of the level is reiterated in the text located in the white box, top right.

Cueing is the process of providing specific prompts or reminders during instruction to reinforce specific action patterns when learning a procedural skill. Pigeonetics handles cueing in a particularly effective way. Each level within Pigeonetics is set up with the same prompts, the same visual representations, and gameplay follows the same order for each level and goal. This
consistency allows for students to easily recognize both the components (e.g. the pigeons’ chromosomes and alleles) required to complete the goal of the level, as well as the process used to complete this goal (e.g. choosing the correct parental pigeons and their respective chromosomes). Additionally, the components of the game that allow the user to navigate within the game, e.g. the menu button, the pause button, volume control, as well as the level goal and the allele reference images all remain in the same locations, represented exactly the same across all levels. The consistency allows players to focus on solving the goal for each level because the repetition of these visuals and gameplay serve as prompts to cue the user with how to interact with the level and complete the goal. Players can use their experience from prior levels to inform their actions on subsequent levels, it allows them to focus on solving the goal of the level instead of trying to decipher new gameplay features or new and differing visuals. Consistency allows for focus and attention to be placed on solving the genetic cross itself and completing the goal of the level. Figure 9 shows level 5 of Pigeonetics, which serves as an example of the different cued components of the game. These include consistent visuals, gameplay mechanics, displayed level goals, as well as control and navigation buttons.
Figure 9

Cueing in Pigeonetics

Note. A screenshot from Pigeonetics showing the consistent visual representations of parental pigeons, chromosomes, alleles and the locations of the level goal, and navigation buttons. Each of these remains consistent across all levels.

Gagné’s final condition for learning is that students should have opportunities for repeated practice. Again, this is an area where Pigeonetics is uniquely situated to provide this condition. In a traditional classroom setting, repetition oftentimes comes in the form of physical, printed worksheets distributed several times over the course of a unit that ask students to demonstrate a specific skill or piece of knowledge. In these cases, the student has almost no agency or autonomy in what they are being asked to practice; printed worksheets do not allow
for each student to focus on a particular aspect of a skill that they themselves would like to practice. As such, if the worksheet the student is assigned does not match the skills that they feel they need to practice, is simply practicing a skill that they may have already mastered and not one that may need reinforcement. This is not the case with Pigeonetics. Some unique features of Pigeonetics are the game’s re-playability, and customizable practice. As mentioned previously, each level of Pigeonetics builds upon the next, with earlier levels having simpler goals and then using the skills practiced in earlier levels to complete later, more complex levels. For example, in level 1 of Pigeonetics, the player is asked to set up a genetic cross that will result in a female pigeon. In level 9, play has progressed to ask the player to breed a female pigeon with a specific type of wing pattern. Even further into the game in level 12, players are asked to breed a female pigeon with a specific wing pattern, and with a head crest. The skills learned in earlier levels are then practiced again in subsequent levels and are required to complete the goals and progress in the game. This is only one aspect of repeated practice seen in Pigeonetics. Another example of repeated practice comes with the player’s ability to choose which skills they would like to practice. At any point during gameplay, a player can click on the pause button which opens up a navigation menu. In this menu, the player can not only view all previous levels and their respective goals, but also choose to return to any of those level to replay them. Figure 10 shows a screenshot of this navigation menu with level choices.
Note. After successfully completing a level, a player may navigate back to that level at any time to replay and practice the skills contained in that level.

For example, let’s say that a player has progressed to level 15, where the goal of the level is to create a genetic cross that will result in a male pigeon with blue coloring and a barred feather pattern. After struggling for a few attempts, the student realizes that they don’t completely understand how feather patterns are inherited. At this point they can pause the game, navigate back to level 9 where feather pattern inheritance was first covered, and replay that level.
and review its accompanying information until they feel that they have mastered that skill. They can then re-open the menu, navigate back to level 15, and re-attempt that level. This feature, which allows students to self-identify skills that they need to practice and provide an immediate space to practice them, is one of the most valuable and impactful features of *Pigeonetics*.

The specific conditions needed to foster learning set forth in the works of Ausubel (2000) and of Gagné, (1988) are: drawing connections to previous knowledge, chunking content or skills into smaller more manageable parts, reviewing prior skills and requisite knowledge, cueing of new information and skills, and providing opportunities for repeated practice are all clearly demonstrated in *Pigeonetics*. As such, this makes *Pigeonetics* a particularly robust example of a digital educational game and an appropriate target for further study.
Chapter III

Research Design and Methods

Participants

This study is a secondary analysis of a data set collected under an IRB approved procedure. Participants of this study were high school students who were enrolled in an academic Biology course as part of their 9th grade science curriculum. Student participants ranged in age from 14-16 years old. The participants attended suburban high school near Pittsburgh, Pennsylvania. The high school contains grades 9-12 and has a student body of approximately 1,193 students. The most recent demographic information for the school district lists the makeup of the school as follows: 87% White, 5% Black, 4% Asian, 3% Hispanic, 1% two or more races, and 0.3% American Indian/Alaskan Native. The student body is 50% male and 50% female. Twenty percent of students receive free or reduced lunch (Moon High School Student Body Data, 2018). The participants of this study were minors, a protected population. As such, both student assent and parental consent forms were required for participation in the study.

Sample Selection

The inclusion criteria to participate in the study are: 1. A group of students enrolled in a science course that would cover the specific Genetics content included in Pigeonetics, 2. A collaborating teacher who could competently deliver both a hands-on lesson and a game-based lesson on the specifically identified Genetics content 3. A science course with multiple class sections with students of approximately equivalent academic performance 4. A school classroom that possessed the necessary materials and equipment to facilitate both the hands-on and game-based lessons appropriately. Based on these criteria, a potential sample population was identified. After identification, communication with a school district teacher was established.
Communication with this collaborating teacher helped to identify specific student populations that would be eligible to participate in the study. This included identifying which class periods of which science courses could participate in the study. Subsequently, this resulted in the quasi-experimental sampling design which saw student participants placed into either the control or experimental conditions based upon existing class schedules. This was done to reduce the amount of disruption to both the collaborating teacher’s and the students’ schedules. Class assignment was done by the school district based on student schedules. The classrooms are considered comparable because no specific criteria were used other than fit with schedule to place students in their class section. Only class periods with students enrolled in academic Biology were selected for participation in the study. Class periods for students enrolled in Honors Biology or Remedial Biology were not included in this study. A power analysis was later conducted as part of the secondary data analysis portion of this study to determine if the sample was adequate for secondary analyses. Additional information about the power analysis can be found in the results section.

After specific class periods were identified for potential inclusion in the study, IRB parental consent forms were distributed to parents. Completed parental consent forms were then collected and student assent forms were distributed to students. Following IRB regulations, students were made aware of any potential risks to participation, as well as their rights to withdraw without penalty from the study at any time. Following this, completed student assent forms were collected and matched with parental consent forms to determine which students were eligible to participate in the study. The initial participant enrollment in the study was 28 students, with 11 students assigned to the control group and 17 assigned to the experimental group. Of these students, one student from the control condition had incomplete data and was removed.
from the study. This student’s incomplete data was removed from the data set and was not included for analysis.

**Measures**

Two survey instruments were used in the study: Genetics Content Knowledge Test #1 and Genetics Content Knowledge Test #2. These instruments were created specifically for the study, as existing instruments which adequately aligned with the Genetics content knowledge contained in *Pigeonetics* were not available. As such, a search was conducted to locate existing validated instruments and assessment items related to Genetics content knowledge. Two instruments and an item database were found. These included: *Genetics Literacy Assessment Instrument* (Bowling 2008), *Genetics Literacy Instrument* (Tsui, 2002), and the *AAAS Project 2061 Science Assessment Item Database* (AAAS Science Assessment, 2018). Each of these were examined to identify specific assessment items that aligned with the content of *Pigeonetics*. These items were then matched to specific NGSS standards that are found within the gameplay of *Pigeonetics*. With potential assessment items located and matched with specific NGSS standards, the assessment items were validated for content alignment by an independent researcher, Susan McClatchy, at The Jackson Laboratory (The Jackson Laboratory, 2019). The Jackson Laboratory is a Genetics and Genomics research institution. McClatchy herself has specific expertise in Genetics curriculum development as well as inquiry-based instruction. McClatchy made specific recommendations as to which assessment items were appropriate for inclusion in the study and verified their alignment with NGSS standards (S. McClatchy, personal communication, October 18th, 2018). Based on McClatchy’s recommendations, the assessment items were organized into two separate instruments, Genetics Content Knowledge Test #1 and Genetics Content Knowledge Test #2.
**Instrument Administration**

Of these instruments, Genetics Content Knowledge Test #1 was administered to the participant groups as both the pre-test and the long-term post-test assessments. Genetics Content Knowledge Test #2 was administered as the immediate post-test. Different assessments were used in an attempt to reduce any testing effect caused by repeated questions. Each instrument consists of 12 questions, three being demographic questions, and the remaining nine questions being multiple choice questions related to genetics content. Of the nine questions related to genetics content, five questions specifically related to declarative knowledge and four questions related to procedural knowledge. Questions were scored as either correct or incorrect, with a point value of one per question. As such, participant responses could earn from zero points to nine points on each assessment.

**Research Design**

The design of the secondary analysis was modeled on the methodology used by Ricci, Salas, and Cannon-Bowers’ paper, “Do Computer Games Facilitate Knowledge Acquisition and Retention?” (Ricci, Salas, Cannon-Bowers, 1996). This methodology follows a pre, immediate post, and long-term post-test model which is outlined in Figure 1. In order to gauge students’ prior genetics content knowledge, a pre-test instrument was administered on Day 1 of the study. On Day 2 of the study, students in the control group participate in a hands-on instructional activity while students in the experimental group complete a game-based instructional activity that includes the use of the DEG, Pigeonetics. On Day 3 of the study, the immediate post-test instrument is administered. On Day 33 of the study, 30 days post instructional activities, the long-term post-test is administered. The administration of the test instruments, as well as the classroom instruction is coordinated by the collaborating classroom teacher. The researcher did
not have direct contact with the student participants during data collection. All student responses were then provided to the researcher to be matched, anonymized, scored, and analyzed.

Threats to Validity

All studies have potential threats to both internal and external validity. Internal threats to validity in multi-group studies include: selection bias, regression to the mean, social interaction, and participant attrition. Specific steps were taken during this study to reduce threats to internal validity. In regard to selection bias, student classrooms were randomly assigned to either the control or experimental condition based only upon their existing class schedules. No significant differences were identified in the academic performance of the control and experimental groups prior to the study. Steps were also taken to reduce social interactions between participant groups to limit any potential influence across groups. This included direct verbal instructions from the study’s collaborating teacher to participants in both groups to complete only the work their group was assigned and to ignore any differences in coursework that students in other class periods may receive. No evidence of interactions regarding study materials between participants groups occurred. Participant attrition was not a major factor in the study, as only one participant’s data was omitted from analysis, due to it being incomplete. The study methodology was examined and it was determined that adequate steps to reduce these threats to internal validity were taken. No major threats to internal validity were identified in this study. External threats to validity threaten the generalizability of a particular study and in multi-group studies include: sampling bias, experimenter effect, Hawthorne effect, testing effect, and situation effect. As with threats to internal validity, specific steps were taken during this study to reduce threats to external validity as well. The participant groups chosen were a representative sample that matched the student demographics enrolled at the school district; however, it should be noted that these
demographics, are not directly representative of the student population of the U.S. as a whole. One of the greatest limitations of educational research is that student demographics vary widely across geographic regions and the in-situ nature of educational research dictates that no single study’s participant group can be representative of all students. As such, replications of studies across various settings, with varied participant groups is suggested to improve the generalizability of the studies’ findings. In regard, to experimenter effect, the study protocol was written to limit the direct contact that the researcher would have with the student participants. With the exception of a brief, 20-minute interaction, where the research activities, student assent, and parental consent topics were explained to potential student participants, the researcher did not have any direct interactions with the student participants. The collaborating teacher, with whom the student participants were already familiar and comfortable, followed the study protocol and lead the study activities that involved direct student participation. In conjunction with these steps, the study methodology along with the IRB approved protocol specified that student participants’ grades in their Biology course would not be impacted by their choice to participate or not participate in the study. Additionally, the study participants’ performance in the study activities themselves would not have a direct impact on their grade in their Biology course. This was done to help alleviate any Hawthorne effect, that is, any change in participants’ behavior due to their knowledge of being directly observed, that may have arisen during the course of the study. Two different tests were created. Genetics Content Knowledge Test #1 was administered during the pretest and long-term post-test and Genetics Content Knowledge Test #2 was administered during as the immediate post-test. Thus, threats due to testing effects were minimized because two different instruments were used during the immediate and long-term post-tests. As such, participant performance on the tests was less likely to be affected by the
exposure to the same questions during the pretest which was 30 days prior. Finally, situation
effect was addressed by taking steps to conduct the study in a setting that was native to both the
student participants as well as the collaborating teacher. Study activities were conducted in the
students’ regular classroom as well as at the established time as their normal Biology class.
Study activities were integrated into the existing curriculum schedule so as to align with the
timeframe that the particular genetics content would be covered in order to introduce as little
disruption to both the students’ and collaborating teacher’s normal school day routine. In conclusion, adequate steps have been taken by the researcher to limit both internal and external
threats to validity in this study.

**Independent and Dependent Variables**

This research study examined one independent variable and its effects on one dependent
variable. More specifically, the two-level independent variable of the study is the type of
classroom instructional activity. The control condition’s independent variable was a hands-on
instructional activity, while the experimental condition’s independent variable was a digital
game-based activity. The dependent variable of the study is student assessment score. Student
assessment scores were measured using two instruments, *Genetics Content Knowledge Test #1*
and *Genetics Content Knowledge Test #2*. These instruments were used to measure student
assessment scores at three separate time points in the study, Day 1, Day 3, and Day 33. Student
assessment scores were treated as a discrete variable, with whole number scores resulting from
correct and incorrect responses on the two instruments.

**Procedures**

Research activities for this study began with the examination of existing study
methodologies in game-based learning literature. After a review of the literature, a target
methodology was identified in Ricci, Salas, and Cannon-Bowers’ 1996 paper, “Do Computer-Based Games Facilitate Knowledge Acquisition and Retention?” This methodology followed a pre-test, immediate post-test, and long-term post-test model that was appropriate for use with the target DEG, Pigeonetics. Slight modifications to Ricci et al.’s study methodology was implemented to better support the research questions of this study. These modifications include: having two types of instructional activities (i.e. hands-on and game-based) versus the original three types of instructional activities (i.e. test-based, text-based, and game-based) as well as modifying the time period in which the long-term post-test was administered, originally 28 days and modified to 30 days, post-instruction. These modifications were made to better support the research questions of the study.

A detailed study protocol that included specific classroom instructional activities that included both hands-on and game-based activities was developed. The study protocol outlined when pre-test assessments, instructional activities, immediate post-test, and long-term post-test assessments were to take place and how specifically they were to be implemented. With a methodology in place, an IRB protocol was written and approved by Duquesne University. Next, a potential study location and participant pool were identified. Because study activities took place in a school setting, relationships were established with a collaborating teacher as well as department and school representatives. A more in-depth examination was undertaken of when in the school’s established curriculum the study activities would fit and be the least disruptive. Specific class periods of the collaborating teacher’s academic Biology course were identified for inclusion in the study as well. Communication about the research, including parental consent forms were distributed to the students’ parents. Additionally, the researcher visited the target class periods to explain the research activities and to distribute assent forms to the potential
student participants. These were later matched with their accompanying parental consent forms to identify which students were eligible to participate in the study activities.

Study activities were scheduled to coincide with the Genetics unit to be covered in the Biology course. Day 1 of study activities saw the administration of the pre-test assessment, *Genetics Content Knowledge Test #1*, by the collaborating teacher to both participant groups. Completed assessments were collected, and returned to the researcher for scoring. Day 2 of study activities saw the control group participate in a hands-on activity. This hands-on activity asks students to follow written instructions for an activity that guides them through constructing a model of a genome through the use of pipe cleaners and beads. Students work through the hands-on activity which includes building the model and answering written questions on an accompanying worksheet. The experimental group participated in a game-based activity that included interacting with the DEG, *Pigeonetics*. Students used laptops to access *Pigeonetics* via visiting [https://learn.genetics.utah.edu/content/pigeons/pigeonetics/](https://learn.genetics.utah.edu/content/pigeons/pigeonetics/). Students followed the embedded instructions within Pigeonetics to play the game, along with completing a companion worksheet alongside their gameplay. Both the control and experimental groups had students complete their respective activities with students working in pairs. Day 3 study activities included the administration of the immediate post-test assessment, *Genetics Content Knowledge Test #2*, by the collaborating teacher to both participant groups. Completed assessments were collected and returned to the researcher for scoring. Days 4-29 all study participants received identical instruction on Genetics content that was part of the collaborating teacher’s established Genetics curriculum. Instructional activities included didactic lecture, diagram interpretation, and scaffolded note-taking. Additional hands-on activities and game-based activities were not included. On Day 30, *Genetics Content Knowledge Test #1* was administered again, this time as
a long-term post-test assessment to both participant groups. Completed assessments were collected and returned to the researcher for scoring.

After collection, all completed assessments were matched then anonymized and then scored. Any incomplete assessments were not scored and were excluded from the data set, with only a single participant’s data being excluded. Correct responses on assessment items received a score of +1, while incorrect responses received a score of zero. Participant scores were then entered into an SPSS database. The original researcher did not conduct data analysis on the data set that was generated by the study. All referenced instruments and materials can be found in Appendix A.

The study looks to examine the aforementioned data set and conduct statistical analyses to answer the outlined research questions.

**Data Analysis**

The current study looks to examine the following research questions:

1. Does game-based instruction using *Pigeonetics* result in greater immediate knowledge acquisition than hands on instruction for genetics declarative knowledge?

2. Does game-based instruction using *Pigeonetics* result in greater immediate knowledge acquisition than hands on instruction for genetics procedural knowledge?

3. Does game-based instruction using *Pigeonetics* result in greater long-term retention than hands-on instruction for genetics declarative knowledge?

4. Does game-based instruction using *Pigeonetics* result in greater long-term retention than hands-on instruction for genetics procedural knowledge?

The researcher puts forward the following hypotheses for consideration:
1. Students who played the DEG, *Pigeonetics* will have greater genetics declarative knowledge scores when compared to students who completed a hands-on activity, immediately following these activities.

2. Students who played the DEG, *Pigeonetics* will have greater genetics procedural knowledge scores when compared to students who completed a hands-on activity, immediately following these activities.

3. Students who played the DEG, *Pigeonetics* will have greater genetics declarative knowledge scores when compared to students who completed a hands-on activity, 30 days after these activities.

4. Students who played the DEG, *Pigeonetics* will have greater genetics procedural knowledge scores when compared to students who completed a hands-on activity, 30 days after these activities.

Each of these hypotheses were tested using a variety of statistical tests using various software packages. G-Power was used to conduct an a-priori power analysis ($\alpha = .05$) to identify appropriate sample sizes for the study. Software package JASP was used to generate descriptive statistics, including sample size, range, mean, standard deviation, skewness, kurtosis, and standard error of mean for each test administrations’ results across groups. Tests for normality using skewness and kurtosis z-scores were calculated to determine if pre-test, immediate post-test, and long-term post-test scores for both groups follow a normal distribution. Change scores were calculated to determine the difference between participant scores from pre-test to immediate post-test, and immediate post-test to long-term post-test across groups. These change scores are referred to as Change Score 1 and Change Score 2 respectively and were used to quantify the amount of change each student participant realized between assessments. In order to
quantify the magnitude of change seen in each group’s change scores, effect size was calculated using Bayesian posterior plot hypothesis testing.
Chapter IV

Results

In an effort to examine the data set fully and thoroughly, both General Linear Model (GLM) and Bayesian analyses were employed. Because of the small sample size of the data set, GLM analyses alone are not sufficient to accurately evaluate the study’s research questions. The study’s small sample size directly impacts GLM analyses’ power, and thus, increases the chances of a Type II error. Combining GLM and Bayesian analyses allows for a more in-depth examination of the data set, and helps to determine if a non-significant result is due to data insensitivity or actual evidence in support of the null hypothesis.

In order to visualize the research questions, Table 1 was generated. Table 1 lists the specific research questions as well as the GLM and Bayesian analyses used to analyze the data, as well as the associated hypotheses. Table 1 was used as an organizational tool to map out the analyses needed to answer the study’s four research questions.

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Data Examined</th>
<th>Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands on instruction for genetics declarative knowledge?</td>
<td>Change Score #1 Declarative Knowledge Questions</td>
<td>Participants in the game condition will have significantly larger Change Score #1 values on declarative knowledge questions than those in the hands-on condition.</td>
</tr>
<tr>
<td>Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands on instruction for genetics procedural knowledge?</td>
<td>Change Score #1 Procedural Knowledge Questions</td>
<td>Participants in the game condition will have significantly larger Change Score #1 values on procedural knowledge questions than those in the hands-on condition.</td>
</tr>
</tbody>
</table>
Does game-based instruction using \textit{Pigeonetics} result in greater long-term retention than hands-on instruction for genetics \textbf{declarative} knowledge? Participants in the game condition will have significantly smaller Change Score \#2 values on declarative knowledge questions than those in the hands-on condition.

Does game-based instruction using \textit{Pigeonetics} result in greater long-term retention than hands-on instruction for genetics \textbf{procedural} knowledge? Participants in the game condition will have significantly smaller Change Score \#2 values on procedural knowledge questions than those in the hands-on condition.

\textit{Note:} All analyses used to evaluate the data were GLM and Bayesian t-tests.

\textbf{Descriptive Statistics}

Crosstabulations of participants’ gender by assigned experimental condition are provided in Table 2. Table 3 shows the calculated chi-square value for gender by experimental condition. The following descriptive statistics were calculated for student scores on the pre-test, immediate post-test, and long-term post-test assessments: mean, standard deviation, maximum score, and minimum score. These values are shown in Table 4.

\textbf{Table 2}

\textit{Participant Gender by Experimental Condition}

<table>
<thead>
<tr>
<th>GENDER</th>
<th>CONDITION</th>
<th>Hands On</th>
<th>Game</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>4</td>
<td>7</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>6</td>
<td>10</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>17</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

\textbf{Table 3}

\textit{Chi-Square value for Gender by Experimental Condition}

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>X^2</td>
<td>0.004</td>
<td>0.95</td>
</tr>
<tr>
<td>N</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

\textit{Note:} * \( p < .05 \)
On the pre-test assessment, students in the hands-on condition had scores ranging from 4.00 to 8.00, and a mean score of 6.0, while students in the game condition had scores ranging from 4.00 to 8.00 and had a mean score of 6.35. Standard deviation for the hands-on student scores was 1.49 and for the game student scores standard deviation was 1.50. On the immediate post-test assessment, scores of students in the hands-on condition ranged from 4.00 to 9.00, with a mean score of 6.4, while scores of students in the game condition ranged from 2.00 to 9.00 and had a mean score of 7.0. Standard deviation for the hands-on student scores was 1.65 and for the game student scores standard deviation was 1.94. On the long-term post-test assessment, students in the hands-on condition had scores ranging from 6.00 to 9.00, and a mean score of 7.0, while students in the game condition also had scores ranging from 6.00 to 9.00 and a mean score of 7.12. Standard deviation for the hands-on student scores was .94 and for the game student scores standard deviation was 1.11.
The same descriptive statistics: mean, standard deviation, maximum score, and minimum score, were also calculated for only the declarative knowledge questions on the pre-test, immediate post-test, and long-term post-test. These values are shown in Table 5.

Table 5
Descriptive Statistics for Student Scores on Pre-test, Immediate Post-Test and Long-Term Post Test for Declarative Knowledge Questions

<table>
<thead>
<tr>
<th></th>
<th>PRETEST DECLARATIVE</th>
<th>IMMEDIATE POST DECLARATIVE</th>
<th>LONGTERM POST DECLARATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hands On</td>
<td>Game</td>
<td>Hands On</td>
</tr>
<tr>
<td>Valid</td>
<td>10</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>3.40</td>
<td>3.53</td>
<td>3.30</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>0.84</td>
<td>1.33</td>
<td>1.42</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Examining only the declarative knowledge questions on the pre-test assessment, students in the hands-on condition had scores ranging from 2.00 to 5.00, and a mean score of 3.4, while students in the game condition had scores ranging from 1.00 to 5.00 and had a mean score of 3.53. Standard deviation for the hands-on student scores was 0.084 and for the game student scores standard deviation was 1.33.

For the declarative knowledge questions on the immediate post-test assessment, students in the hands-on condition had scores ranging from 1.00 to 5.00, and a mean score of 3.30, while students in the game condition had scores ranging from 0 to 5.00 and a mean score of 3.71. Standard deviation for the hands-on student scores was 1.42 and for the game student scores standard deviation was 1.69.

For the declarative knowledge questions on the long-term post-test assessment, students in the hands-on condition had scores ranging from 2.00 to 5.00, and a mean score of 3.9, while students in the game condition had scores ranging from 2.00 to 5.00 and a mean score of 3.67.
Standard deviation for the hands-on student scores was 1.00 and for the game student scores standard deviation was 0.93.

Mean, standard deviation, maximum score, and minimum score, were also calculated for only the procedural knowledge questions on the pre-test, immediate post-test, and long-term post-test. These values are shown in Table 6.

Table 6
Descriptive Statistics for Student Scores on Pre-test, Immediate Post-Test and Long-Term Post-Test for Procedural Knowledge Questions

<table>
<thead>
<tr>
<th></th>
<th>PRETEST PROCEDURAL</th>
<th>IMMEDIATE POST PROCEDURAL</th>
<th>LONGTERM POST PROCEDURAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hands On</td>
<td>Game</td>
<td>Hands On</td>
<td>Game</td>
</tr>
<tr>
<td>Valid</td>
<td>10</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>2.6</td>
<td>2.82</td>
<td>3</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>0.97</td>
<td>0.81</td>
<td>0.94</td>
</tr>
<tr>
<td>Minimum</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Maximum</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Looking only at the procedural knowledge questions on the pre-test assessment, students in the hands-on condition had scores ranging from 1.00 to 4.00, and a mean score of 2.60, while students in the game condition had scores ranging from 1.00 to 4.00 and a mean score of 2.82. Standard deviation for the hands-on student scores was 0.97 and for the game student scores standard deviation was 0.81.

For the procedural knowledge questions on the immediate post-test assessment, students in the hands-on condition had scores ranging from 1.00 to 4.00, and a mean score of 3.0, while students in the game condition had scores ranging from 2.00 to 4.00 and a mean score of 3.35.
Standard deviation for the hands-on student scores was 0.94 and for the game student scores standard deviation was 0.61.

On the long-term post-test assessment procedural knowledge questions, students in the hands-on condition had scores ranging from 2.00 to 4.00, and a mean score of 3.1, while students in the game condition had scores ranging from 3.00 to 4.00 and had a mean score of 3.47. Standard deviation for the hands-on student scores was 0.88 and for the game student scores standard deviation was 0.51.

**Inferential Statistics**

*Independent Samples T-tests Pre-test Scores on All Pre-test Questions*

In order to determine if both participant groups started with equivalent knowledge before receiving instruction, a GLM independent samples t-test was conducted. Participant scores on the pre-test were compared between groups across all questions. The results of this test are seen in Table 7.

**Table 7**

*GLM Independent Samples T-test Participant Scores on Pre-Test: Hands-On v. Game*

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
<th>t</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRETEST SCORE</td>
<td>-0.59</td>
<td>25</td>
<td>0.56</td>
</tr>
</tbody>
</table>

*Note.* Student’s t-test.

The GLM independent samples t-test on participants’ pre-test scores resulted in a p-value of 0.56 at significance level of $\alpha=0.05$.

In addition, a Bayesian independent samples t-test was also conducted on participant scores across all pre-test questions. The results of this test are seen in and Figure 11.
As expected, the $BF_{10} = 0.42$ of the comparison of pre-test scores between the hands-on and game groups indicated support for the null hypothesis that the mean scores of the two groups were equivalent.

In regard to declarative knowledge, a GLM independent samples t-test was conducted to determine if both participant groups started with equivalent declarative knowledge before receiving instruction. Participant scores on the declarative knowledge pre-test questions were compared between groups across only declarative knowledge questions. The results of this test are seen in Table 8.

Table 8
GLM Independent Samples T-test Participant Scores on Declarative Knowledge Pre-Test Questions

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
<th>t</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRETEST SCORE</td>
<td>-0.28</td>
<td>25</td>
<td>0.79 a</td>
</tr>
<tr>
<td>DECLARATIVE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Student's t-test.
The GLM independent samples t-test on participants’ pre-test scores on declarative knowledge questions resulted in a p-value of 0.79 at significance level of α = 0.05.

In addition, a Bayesian independent samples t-test was also conducted on participant scores across declarative knowledge pre-test questions. The results of this test are seen in Figure 12.

**Figure 12**  
*Bayesian Independent Samples T-test Participant Scores on Declarative Knowledge Pre-Test Questions*

As expected, the BF$_{10} = 0.38$ of the comparison of pre-test scores between the hands-on and game groups on declarative knowledge questions indicated support for the null hypothesis that the mean scores of the two groups were equivalent.

In regard to procedural knowledge, a GLM independent samples t-test was conducted to determine if both participant groups started with equivalent procedural knowledge before receiving instruction. Participant scores on the procedural knowledge pre-test questions were compared between groups across only procedural knowledge questions. The results of this test are seen in Table 9.
Table 9

GLM Independent Samples T-test Participant Scores on Procedural Knowledge Pre-Test Questions

<table>
<thead>
<tr>
<th></th>
<th>t</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRETEST SCORE</td>
<td>-0.65</td>
<td>25</td>
<td>0.52</td>
</tr>
<tr>
<td>PROCEDURAL</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Student's t-test.

The GLM independent samples t-test on participants’ pre-test scores on procedural knowledge questions resulted in a p-value of 0.52 at significance level of $\alpha=0.05$.

In addition, a Bayesian independent samples t-test was also conducted on participant scores across procedural knowledge pre-test questions. The results of this test are seen in Figure 13.

**Figure 13**

*Bayesian Independent Samples T-test Participant Scores on Procedural Knowledge Pre-Test Questions*
As expected, the BF$_{10} = 0.43$ of the comparison of pre-test scores between the hands-on and game groups on procedural knowledge questions indicated support for the null hypothesis that the mean scores of the two groups were equivalent. This is what was expected.

*Independent Samples T-tests on Change Scores*

In order to quantify the change in each participant’s score from the pre-test to the immediate post-test a new variable was created. This variable was named “Change Score 1” with positive values indicating an increase in participant score from pre-test to immediate post-test and negative values indicating a decrease in participant score from pre-test to immediate post-test. Both GLM independent samples t-tests and Bayesian independent samples t-tests were conducted on Change Score 1 across all questions. The results of these analyses can be seen in Table 10 and Figure 14.

**Table 10**

*GLM Independent Samples T-test Change Score 1 All Questions: pre-test to immediate post-test*

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHANGE_SCORE_1</td>
<td>-0.38</td>
<td>25</td>
<td>0.35</td>
<td>-0.152</td>
</tr>
</tbody>
</table>

*Note.* For this test, the alternative hypothesis specifies that group *Hands On* is less than group *Game*.

The GLM independent samples t-test on participants’ Change Score #1 resulted in a p-value of 0.353 and a Cohen’s d value of -0.152 at significance level of $\alpha = 0.05$. 

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As expected, the BF\textsubscript{10} = 0.48 of the comparison of Change Score #1 between the hands-on and game groups across all questions indicated support for the alternative hypothesis. This indicates that the mean Change Score #1 of the two groups were not equivalent, with the scores of the game condition group being higher than those of the hands-on group.

Looking more specifically at the change in participant scores related to immediate declarative knowledge acquisition, again, both GLM and Bayesian independent samples t-tests were conducted. These analyses were aimed at answering research question #1, “Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands on instruction for genetics declarative knowledge?” The results of these analyses can be seen in Table 11 and Figure 15.
Table 11

*GLM Independent Samples T-test Change Score 1 Declarative Knowledge Questions: pre-test to immediate post-test*

<table>
<thead>
<tr>
<th>CHANGE_SCORE_1 DECLARATIVE</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.458</td>
<td>25</td>
<td>0.325</td>
<td>0.183</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* For this test, the alternative hypothesis specifies that group *Hands On* is less than group *Game.*

*Note.* Student’s t-test.

The GLM independent samples t-test on participants’ Change Score #1 for declarative knowledge questions only, resulted in a p-value of 0.325 and a Cohen’s d value of -0.183 at significance level of α= 0.05.

**Figure 15**

*Bayesian Independent Samples T-test Change Score 1 Declarative Knowledge Questions: pre-test to immediate post-test*
As expected, the $BF_{10} = 0.52$ of the comparison of Change Score #1 between the hands-on and game groups across declarative questions indicated support for the alternative hypothesis. This indicates that the mean scores of the two groups were not equivalent, with the scores of the game condition group being higher than those of the hands-on group.

In addition, the change in participant scores related to immediate procedural knowledge acquisition was examined. This was done through the use of GLM and Bayesian independent samples t-tests. These analyses were aimed at answering research question #2, “Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands on instruction for genetics procedural knowledge? The results of these analyses can be seen in Table 12 and Figure 16.

**Table 12**

*GLM Independent Samples T-test Change Score 1 Procedural Knowledge Questions: pre-test to immediate post-test*

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHANGE_SCORE_1_PROCEDURAL</td>
<td>-0.376</td>
<td>25</td>
<td>0.355</td>
<td>-0.150</td>
</tr>
</tbody>
</table>

*Note.* For this test, the alternative hypothesis specifies that group *Hands On* is less than group *Game*.

*Note.* Student's t-test.

The GLM independent samples t-test on participants’ Change Score #1 for procedural knowledge questions only, resulted in a p-value of 0.355 and a Cohen’s d value of -0.150 at significance level of $\alpha = 0.05$. 

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As expected, the BF10 = 0.48 of the comparison of Change Score #1 between the hands-on and game groups for procedural knowledge questions indicated support for the alternative hypothesis that the mean scores of the two groups were not equivalent, with scores of the game condition group being higher than those of the hands-on group.

To answer research question #3, “Does game-based instruction using Pigeonetics result in greater long-term retention than hands-on instruction for genetics declarative knowledge?” and additional variable was created. “Change Score 2” quantifies the change in each participant’s score, from the immediate post-test to the long-term post-test. Negative values for Change Score 2, are expected which would indicate participants’ learning loss from the immediate post-test to the long-term post-test. This learning loss can be measured in order to gauge participants’ retention of genetics knowledge. Both GLM independent samples t-tests and Bayesian independent samples t-tests were conducted on Change Score 2 across all questions. The results of these analyses can be seen in Table 13 and Figure 17.
Table 13

*GLM Independent Samples T-test Change Score 2 All Questions: immediate post-test to long-term post-test*

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHANGE_SCORE_2</td>
<td>0.68</td>
<td>25</td>
<td>0.25</td>
<td>0.27</td>
</tr>
</tbody>
</table>

*Note.* For this test, the alternative hypothesis specifies that group *Hands On* is greater than group *Game*.

*Note.* Student's t-test.

The GLM independent samples t-test on participants’ Change Score #2 resulted in a p-value of 0.25 and a Cohen’s d value of 0.27 at significance level of $\alpha = .05$.

**Figure 17**

*Bayesian Independent Samples T-test Change Score 2 All Questions: immediate post-test to long-term post-test*

In an unexpected result, the $BF_{10} = 0.63$ of the comparison of Change Score #2 between the hands-on and game groups across all questions indicated support for the null hypothesis that the mean scores of the two groups were equivalent.

Looking more specifically at the change in participant scores related to long-term retention of declarative knowledge, again, both GLM and Bayesian independent samples t-tests
were conducted. The results of these analyses can be seen in Table 14 and Figure 18.

Table 14

*GLM Independent Samples T-test Change Score 2 Declarative Knowledge Questions: immediate post-test to long-term post-test*

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHANGE_SCORE_2 DECLARATIVE</td>
<td>1.055</td>
<td>25</td>
<td>0.151</td>
<td>0.421</td>
</tr>
</tbody>
</table>

*Note.* For all tests, the alternative hypothesis specifies that group *Hands On* is greater than group *Game*.

*Note.* Student's t-test.

The GLM independent samples t-test on participants’ Change Score #2, resulted in a p-value of 0.151 and a Cohen’s d value of 0.421 at significance level of α= 0.05.

Figure 18

*Bayesian Independent Samples T-test Change Score 2 Declarative Knowledge Questions: immediate post-test to long-term post-test*
In an unexpected result, the BF_{10} = 0.89 of the comparison of Change Score #2 between the hands-on and game groups across declarative knowledge questions indicated support for the null hypothesis that the mean scores of the two groups were equivalent.

To answer research question #4, “Does game-based instruction using Pigeonetics result in greater long-term retention than hands-on instruction for genetics procedural knowledge?” Change Score 2 was examined again. Positive values for Change Score 2 indicate an increase in participant score from immediate post-test to long-term post-test and negative values indicating a decrease in participant score from pre-test to immediate post-test. Both GLM independent samples t-tests and Bayesian independent samples t-tests were conducted on Change Score 2 across procedural knowledge questions. The results of these analyses can be seen in Table 15 and Figure 19.

**Table 15**

*GLM Independent Samples T-test Change Score 2 Procedural Knowledge Questions: immediate post-test to long-term post-test*

<table>
<thead>
<tr>
<th>Independent Samples T-Test</th>
<th>t</th>
<th>df</th>
<th>p</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHANGE_SCORE_2_PROCEDURAL</td>
<td>-0.054</td>
<td>25</td>
<td>0.521</td>
<td>-0.022</td>
</tr>
</tbody>
</table>

*Note.* For all tests, the alternative hypothesis specifies that group *Hands On* is greater than group *Game.*

*Note.* Student's t-test.

The GLM independent samples t-test on participants’ Change Score #1 for procedural knowledge questions only, resulted in a p-value of 0.521 and a Cohen’s d value of -0.022 at significance level of $\alpha = 0.05$. 

63
In an unexpected result, the $BF_{10} = 0.35$ of the comparison of Change Score #2 between the hands-on and game groups across procedural knowledge questions indicated support for the null hypothesis that the mean scores of the two groups were equivalent.

To summarize, both GLM and Bayesian analyses were utilized to examine the study’s four research questions:

1. Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands-on instruction for genetics declarative knowledge?
2. Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands-on instruction for genetics procedural knowledge?
3. Does game-based instruction using Pigeonetics result in greater long-term retention than hands-on instruction for genetics declarative knowledge?
4. Does game-based instruction using Pigeonetics result in greater long-term retention than hands-on instruction for genetics procedural knowledge?

Analyses showed that the hands-on and game condition groups had equivalent levels of both declarative and procedural Genetics knowledge on the pre-test assessment. Participants in the game condition scored .6 points higher on the immediate post-test than participants in the hands-on condition, although this difference in mean scores was non-significant. Change Score #1 was calculated to measure participants’ acquisition of genetics knowledge from the pre-test to the immediate post-test assessment. Significant differences between the hands-on and game condition groups’ Change Score #1 values were observed, with participants in the game condition having higher Change Score #1 values than those in the hands-on condition. These differences were observed both in declarative and procedural knowledge, as well as across all questions combined. Participants in the game condition scored 0.12 points higher than participants in the hands-on condition on the long-term post-test, although this difference in mean scores was non-significant. Change Score #2 was calculated to measure participants’ retention of genetics knowledge from the immediate post-test to the long-term post-test. Participants in the game condition had lower Change Score #2 values than participants in the hands-on condition, on declarative knowledge questions and all questions combined. However, participants in the game condition had higher Change Score #2 values on procedural knowledge questions. Table 16 contains a summary of the study’s findings in relation to each research question. It should be noted that the findings displayed in Table 16 were generated from Bayesian analyses, as none of the GLM analyses found in significant differences between groups.
<table>
<thead>
<tr>
<th>Research Question</th>
<th>Results</th>
<th>Alternative Hypothesis</th>
<th>Null Hypothesis Accepted/Rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does game-based instruction using <em>Pigeonetics</em> result in greater immediate knowledge acquisition than hands on instruction for genetics declarative knowledge?</td>
<td>A significant difference between participants’ Change Score #1 values on declarative knowledge questions were observed, with game condition participants having higher scores.</td>
<td>Participants in the game condition will have significantly larger Change Score #1 values on declarative knowledge questions than those in the hands-on condition.</td>
<td>Rejected</td>
</tr>
<tr>
<td>Does game-based instruction using <em>Pigeonetics</em> result in greater immediate knowledge acquisition than hands on instruction for genetics procedural knowledge?</td>
<td>A significant difference between participants’ Change Score #1 values on procedural knowledge questions were observed, with game condition participants having higher scores.</td>
<td>Participants in the game condition will have significantly larger Change Score #1 values on procedural knowledge questions than those in the hands-on condition.</td>
<td>Rejected</td>
</tr>
<tr>
<td>Does game-based instruction using <em>Pigeonetics</em> result in greater long-term retention than hands-on instruction for genetics declarative knowledge?</td>
<td>No significant difference between game and hands-on participants’ Change Score #2 values on declarative knowledge questions were observed.</td>
<td>Participants in the game condition will have significantly smaller Change Score #2 values on declarative knowledge questions than those in the hands-on condition.</td>
<td>Accepted</td>
</tr>
<tr>
<td>Does game-based instruction using <em>Pigeonetics</em> result in greater long-term retention than hands-on instruction for genetics procedural knowledge?</td>
<td>No significant difference between game and hands-on participants’ Change Score #2 values on procedural knowledge questions were observed.</td>
<td>Participants in the game condition will have significantly smaller Change Score #2 values on procedural knowledge questions than those in the hands-on condition.</td>
<td>Accepted</td>
</tr>
</tbody>
</table>

*Note:* All analyses used to evaluate the data were GLM and Bayesian t-tests.
Chapter V

Discussion

Conclusions

This study evaluated a pre-existing data set that included participant scores across a pre-test, immediate post-test, and long-term post-test. Participants were assigned to either a game-based condition, where they played the digital educational game, Pigeonetics, or to a hands-on condition where they completed a hands-on activity. Based on the data from the pre-test assessment, participants began the study with equivalent levels of both declarative and procedural genetics knowledge. An examination of each of the study’s research questions and the associated results can be seen below.

Research question #1 asked “Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands on instruction for genetics declarative knowledge?” This question looked specifically at participants’ change in scores from the pre-test to the immediate post-test. Analysis of the data indicated that participants in the game condition acquired more declarative genetics knowledge than those participants in the hands-on condition. This provides support for research hypothesis #1, “Students who played the DEG, Pigeonetics will have greater genetics declarative knowledge scores when compared to students who completed a hands-on activity, immediately following these activities.”

Similarly, research question #2, “Does game-based instruction using Pigeonetics result in greater immediate knowledge acquisition than hands on instruction for genetics procedural knowledge? Again, this question examined participants’ change in scores from the pre-test to the immediate post-test. Here too, participants in the game-based condition acquired more procedural knowledge than those participants in the hands-on condition. This provides support
for research hypothesis #2, “Students who played the DEG, Pigeonetics will have greater genetics procedural knowledge scores when compared to students who completed a hands-on activity, 30 days after these activities.

Research question #3 asked “Does game-based instruction using Pigeonetics result in greater long-term retention than hands-on instruction for genetics declarative knowledge?” Here, participants’ retention of declarative genetics knowledge was measured by the change in scores from the immediate post-test to the long-term post-test. Unlike research questions #1 and #2, scores between the game and hands-on conditions were equivalent, indicating that the groups retained similar amounts of declarative genetics knowledge. This provides support for rejecting research hypothesis #3, “Students who played the DEG, Pigeonetics will have greater genetics declarative knowledge scores when compared to students who completed a hands-on activity, 30 days after these activities.”

The final research question, Research question #4 asked “Does game-based instruction using Pigeonetics result in greater long-term retention than hands-on instruction for genetics procedural knowledge?” Similar to Research question #3, participants retention of procedural genetics knowledge was measured by the change in scores from the immediate post-test to the long-term post-test. As with question #3, scores between the hands-on and game conditions were equivalent, indicating that the groups also retained similar amounts of procedural knowledge. This provides support for rejecting research hypothesis #4, “Students who played the DEG, Pigeonetics will have greater genetics procedural knowledge scores when compared to students who completed a hands-on activity, 30 days after these activities.”
Based on the data analysis and subsequent support for two of the study’s research hypotheses, it can be concluded that the DEG, *Pigeonetics*, is an effective tool for both declarative and procedural genetics immediate knowledge acquisition. When compared to hands-on learning activity, students who played *Pigeonetics* gain more declarative and procedural genetics knowledge than their peers. Alternatively, this benefit of DEG did not translate as incrementally beneficial in the retention of genetics knowledge over hands-on instruction in the longer term. In evaluating students’ retention of declarative and procedural genetics knowledge, *Pigeonetics* and the hands-on activity resulted in equivalent outcomes. Originally, scores on the long-term post-test were predicted to be lower than those on the immediate post-test, as it would be expected that students would forget some of the genetics knowledge in the 30-day span between the learning activities and the long-term post-test. However, the opposite was observed, with both the game and hands-on students improving their scores from immediate post-test to long-term post-test. This phenomenon could be the result of subsequent learning opportunities which occurred between the dates of the immediate and long-term post-test. These learning opportunities could have included opportunities for practice via homework or in-class assignments, re-teaching via direct instruction, or content review activities. If any of these activities occurred, this could have positively impacted the amount of both declarative or procedural knowledge that was retained at the 30-day time point.

**Implications**

*Digital Educational Games for Knowledge Acquisition*

The study findings have several implications which are relevant to the existing body of literature. First, this study helps to add support to the theory that games can be effective tools for knowledge acquisition, as echoed in works by Boeker (2013), Coller (2009), Cowen (2002), De
Freitas (2018), Kanthan (2011), Ricci (2009), Schuh (2008), Wilson (2018), and Wong (2007). This growing body of literature provides evidence that educational games, when used appropriately, can have improved learning outcomes regarding immediate knowledge acquisition, especially when compared to activities like didactic lecture. Why is this important? It is no secret that teachers’ instructional time is a finite resource; if a specific teaching methodology or learning activity can provide improved learning outcomes, it is to the students’ benefit for teachers to utilize it. Digital educational games are uniquely positioned to provide increased immediate knowledge acquisition over traditional instructional activities like didactic lectures, non-interactive media, or hands-on activities. Thus, the results of this study suggest that teachers could improve their students' learning by incorporating DEGs into their curriculum plans. It is also possible that additional, subsequent, opportunities to interact with DEGs may have the ability to impact students’ knowledge retention.

It should be noted, however, that it is still unclear if DEGs have the ability to better support content knowledge retention than other learning activities. As discussed previously, the current American educational system places high importance on student performance on standardized tests. As such, large portions of classroom instructional time are devoted to re-teaching content in order to prepare students for impending standardized tests. Reteaching in and of itself uses large amounts of valuable instructional time. The use of DEGs not only as learning activities, but also as opportunities for practice, could reduce the demand for time-costly reteaching activities. Students familiarity and possible enjoyment of DEG-based classroom activities may even prove DEGs to be more effective than traditional re-teaching methodologies. If DEGs clearly supported content knowledge retention at better rates than other learning activities, it would be beneficial for teachers to utilize them, in an effort to reduce the amount
instructional time dedicated to re-teaching material in advance of standardized tests. Additional research in this area is needed to determine if DEGs could support higher knowledge retention rates and their optimal use-case scenarios in the classroom.

**Digital Educational Games for Declarative and Procedural Knowledge**

More specifically, the DEG *Pigeonetics* appears to support the acquisition of both declarative and procedural Genetics knowledge equally. While both participant groups saw improvement in their scores from the pre-test to the immediate post-test, participants who played *Pigeonetics* improved their scores by significantly more than did those participants who completed a hands-on activity. This improvement was observed in both declarative and procedural genetics knowledge. This lends further support to the work of Ausubel (2000) and Gagné (1988) in that DEGs, and as shown here specifically, *Pigeonetics*, provides conditions for learning. Notably, *Pigeonetics* can support declarative knowledge acquisition though the incorporation of “chunked” content in individual levels of gameplay, and in the connections to prior knowledge seen in the increasing difficulty in subsequent levels of gameplay. *Pigeonetics* also supports the acquisition of procedural knowledge using cueing, seen in the use of repeated game mechanics in each level, (i.e. the actions within each level of gameplay are the same.) Additionally, cueing is seen in the presentation of each level’s goal, with goals being presented in the same manner across each level of gameplay. Furthermore, *Pigeonetics* supports the acquisition of procedural knowledge by offering repeated opportunities for practice. These repeated opportunities, with little negative consequence for failure, are seen by the replay-ability of each level of the game.
Digital Educational Games as Science Inquiry

The National Academies' National Research Council’s NGSS call for the use of teaching strategies that support science as inquiry (2000, 2013). Science as inquiry incorporates various components, such as: asking questions, making observations, constructing hypotheses and predictions, followed by testing to collect data and analyzing data, to draw conclusions. The DEG Pigeonetics supports these components of science as inquiry and does so in a low-risk environment. This low-risk environment is provided by the game itself. Students can attempt to solve the problems put forth in each level of gameplay in Pigeonetics, with little negative consequences for failure. The design of the game allows students to re-attempt any level, and does not penalize students for in-game failures. This low-risk environment can help to alleviate the feelings of anxiety sometimes experienced by students when failure occurs in other, non-game, activities. Students who play the game ask questions, make observations, test hypotheses and draw conclusions, all within the gameplay of Pigeonetics. It can be suggested that the low-risk format of DEGs allows students to participate in science as inquiry with fewer anxieties than are seen in learning activities, such as laboratory experiments. Although failure is possible within the gameplay of DEGs, the consequences of that potential failure are low-stakes. Students can simply re-attempt a level or problem within the game, as opposed to a failure in a laboratory experiment, which can “waste” physical materials, time, and has much higher chances of producing feelings of anxiety. Therefore, DEGs appear to provide opportunities for investigating, evaluating, discussing, and creating, in a safe, low-risk setting, which is preferable to other, physical hands-on, laboratory activities.

Study Limitations

As with all research, this study contains several limitations. The data set being used in the study was sourced from previous research conducted by Duquesne University faculty and was
collected from a single high-school course taught by one teacher. Because of this, certain limitations were outside of the researcher’s direct control. Because the data set contained information from only a single teacher’s course, participant scores could have been impacted by teacher quality. If the teacher was unable to provide the appropriate and equal support for both the game and hands-on activities equally, this could impact participant scores and potentially be a threat to internal validity of the study.

Additionally, because the original data set was collected from a single suburban public high school, the results may not be generalizable across other school settings whose demographics and characteristics differ greatly from those of the school studied, a threat to the external validity of this study.

Another limitation lies within the assessment instruments used to evaluate participants’ genetics knowledge. The assessment instruments used to evaluate participants’ genetics knowledge were constructed by sourcing questions from existing, validated genetics knowledge instruments. However, due to the limited scope of the genetics content contained within the DEG being studied, the number of relevant questions was limited. The questions sourced from previously validated genetics instruments were matched to content standards from the Next Generation Science Standards (NGSS) and matched to specific content within Pigeonetics, the DEG being studied.

The final limitation of the study involves the lack of qualitative data. Unfortunately, the data set being examined does not contain qualitative information from participants. If qualitative data had been gathered in the form of participant interviews or survey responses, a deeper and more complex understanding of participants’ preference or aversion to using DEGs in the classroom and its impacts participant performance on the assessments may have been possible.
Recommendations for Future Research

To address the limitations of the current study, a series of recommendations can be made for future research. These recommendations relate mostly to edits that can be made to the setting of future studies as well as the instruments used in the studies.

In future iterations of this research, recruiting multiple teachers at different and varied high schools is suggested. Using multiple teachers at different high schools would help to alleviate issues related to teacher quality and its impact on the learning activities conducted (game and hands-on) and the resulting participant scores. Recruiting teachers at various high schools would also be beneficial. Additionally, the use of a survey instrument about teacher attitudes and opinions related to DEG and their use in the classroom could provide valuable insights. Furthermore, collecting data about selected teachers’ effectiveness in the classroom can shed light on whether teacher quality impacts the effectiveness of DEGs. Also, future iterations of research should include an evaluation of the quality DEG being studied, should be undertaken. Finally, adding additional instances of DEG use in the classroom across a longer time period could determine if the amount of time spent playing a DEG impacts its effectiveness. This, coupled with a standardized and documented amount of re-teaching or homework practice would help to build a more robust understanding of DEGs as tools to support knowledge acquisition and retention. Identifying high schools in a larger geographic area, with varied student demographics, and/or different socio-economic conditions, would provide strength to future studies and increase the generalizability of the study results.

Additionally, the development and validation of several new assessment questions directly aligned to the content contained in Pigeonetics would help to make the findings of this study more robust. Also, the addition of questions to evaluate emotional aspects such as self-
efficacy, confidence, or enjoyment of the activity should be included in the updated instruments. The testing and validation of the new assessment questions, to be incorporated into the pre-test, immediate post-test, and long-term post-test, would be preferable to the re-use of questions across assessments.

The implementation of several of the suggested study improvements may help to generate more robust and generalizable findings in future iterations of this or related studies.
References

“AAAS Science Assessment.” AAAS Science Assessment Project 2061, American Association for the Advancement of Science, 2018, assessment.aaas.org/topics/1/RH##/0.


The Jackson Laboratory. “Susan McClatchy.” The Jackson Laboratory, 2019, www.jax.org/people/susan-mcclatchy#.


Appendix A

Genetics Content Knowledge Test #1

After reading each of the questions, please choose the best answer.

* Required

1. Name

2. Date

3. Gender *
   Mark only one oval.
   ○ Male
   ○ Female
   ○ Other

4. In sexually reproducing organisms, such as humans, which of the following statements is TRUE about the DNA found in the cells of the children? *
   Mark only one oval.
   ○ All of the DNA in the cells of the children contains genetic information from just one of the parents.
   ○ Half of the DNA in the cells of the children contains genetic information from one parent, and half of the DNA contains genetic information from the other parent.
   ○ Some of the DNA in the cells of the children contains genetic information from each parent, but the amount of DNA containing information from each parent cannot be predicted.
   ○ Most of the DNA in the cells of the sons contains genetic information from the father, and most of the DNA in the cells of the daughters contains genetic information from the mother.

5. In sexually reproducing organisms, such as humans, which of the following is TRUE about the sex cells in an individual human? *
   Mark only one oval.
   ○ The sex cells in an individual human contain half the number of DNA molecules as other kinds of cells in that human's body.
   ○ The sex cells in an individual human contain the same number of DNA molecules as other kinds of cells in that human's body.
   ○ The sex cells in an individual human contain double the number of DNA molecules as other kinds of cells in that human's body.
   ○ The number of DNA molecules in the sex cells in an individual human's body is different for different sex cells in that human's body.
6. In sexually reproducing organisms, such as humans, which of the following statements is TRUE about the genetic information that is passed from parents to children?
Mark only one oval.
- All of the genetic information comes from one of the parents.
- Half of the genetic information comes from each of the parents.
- Some of the genetic information comes from each of the parents, but the amount that comes from each parent cannot be predicted.
- Sons receive most of their genetic information from their fathers, and daughters receive most of their genetic information from their mothers.

7. In humans, the allele H for Huntington disease (a hereditary disease that results in degeneration of the nervous system leading to convulsions and premature death) is dominant to the normal allele h. Given that John is found to have Huntington disease, his genotype may probably be:
Mark only one oval.
- HH
- Hh
- Hh or hh
- Don't know

8. In garden peas, white flowers are recessive to purple flowers. Suppose we use W for the dominant allele and w for the recessive allele, what is the genotype of a plant with white flowers?
Mark only one oval.
- Ww
- Ww or ww
- ww
- Don't know

9. Which of the following contain genetic information?
Mark only one oval.
- Chromosomes and DNA molecules
- Chromosomes but not DNA molecules
- DNA molecules but not chromosomes
- Neither chromosomes nor DNA molecules

10. What is the relationship among genes, DNA, and chromosomes?
Mark only one oval.
- Genes are composed of DNA and lie within chromosomes.
- Genes are separate entities from either DNA or chromosomes.
- Genes are found only in chromosomes and not DNA.
- Genes are found only in DNA and not chromosomes.
- Chromosomes are composed of genes but not DNA.
11. In dogs, the gene allele (e) for drooping ears is recessive to E for erect ears. A male dog with genotype Ee was mated to a female dog with genotype ee and gave birth to a litter of 16 puppies. What is the expected proportion of drooping-eared puppies in the litter?

Mark only one oval.

- [ ] A quarter
- [ ] Half
- [ ] All
- [ ] Don’t know

12. Cystic fibrosis (CF) is a recessive disorder, meaning that an individual must have two copies of an abnormal CF gene to be affected. What is the probability that a child of two individuals who each have one copy of the abnormal gene will be affected with CF?

Mark only one oval.

- [ ] 0%
- [ ] 25%
- [ ] 50%
- [ ] 66%
- [ ] 75%
Genetics Content Knowledge Test #2
After reading each of the questions, please choose the best answer.

* Required

1. Name 

2. Date 

3. Gender *
   Mark only one oval.
   ○ Male
   ○ Female
   ○ Other

4. In sexually reproducing organisms, such as humans, which of the following statements is TRUE about the chromosomes found in the cells of the children?
   Mark only one oval.
   ○ All of the chromosomes in the cells of the children contain genetic information from just one of the parents.
   ○ Half of the chromosomes in the cells of the children contain genetic information from one parent, and half of the chromosomes contain genetic information from the other parent.
   ○ Some of the chromosomes in the cells of the children contain genetic information from each parent, but the number of chromosomes containing information from each parent cannot be predicted.
   ○ Most of the chromosomes in the cells of the sons contain genetic information from the father, and most of the chromosomes in the cells of the daughters contain genetic information from the mother.

5. In sexually reproducing organisms, such as humans, which of the following statements is TRUE about the DNA that is passed from parents to children?
   Mark only one oval.
   ○ All of the DNA comes from one of the parents.
   ○ Half of the DNA comes from each of the parents.
   ○ Some of the DNA comes from each of the parents, but the amount that comes from each parent cannot be predicted.
   ○ Sons receive most of their DNA from their fathers, and daughters receive most of their DNA from their mothers.
6. In sexually reproducing organisms, such as humans, which of the following is TRUE about the DNA in each of the body cells (any cell in the body except a sex cell) of a daughter and her father?

Mark only one oval.

- Less than 50% of the DNA in each of the daughter’s body cells is from her father.
- Exactly 50% of the DNA in each of the daughter’s body cells is from her father.
- More than 50% of the DNA in each of the daughter’s body cells is from her father.
- Each type of body cell in the daughter contains a different amount of DNA from her father.

7. The ability to roll the tongue is a dominant trait determined by a pair of genes (R and r). John is a tongue-roller. His genotype may probably be:

Mark only one oval.

- RR
- Rr
- RR or Rr
- Don't Know

8. According to Australian State Screening Laboratories, about one in every 2500 newborn babies in Australia has cystic fibrosis, a genetic disorder due to a recessive gene on the chromosome seven. The symptoms include respiratory and digestive problems and early death. Which one of the following genotypes would indicate that a baby suffers from cystic fibrosis?

Mark only one oval.

- CC
- Cc
- cc
- Don't Know

9. What is the relationship between DNA and chromosomes in higher organisms?

Mark only one oval.

- Chromosomes are found within DNA.
- DNA is found within chromosomes.
- There is no difference between DNA and chromosomes.
- DNA and chromosomes are completely separate structures.
- Chromosomes produce DNA.

10. In guinea pigs, black coat colour is dominant to white. If we use "B" for the dominant allele and "b" for the recessive allele and two guinea pigs of genotype Bb were crossed to produce eight offspring. Which of the following best describes the phenotypes of the offspring?

Mark only one oval.

- All of them are black.
- Most of them are white and others black.
- Most of them are black and others white.
- Don't know.
11. Sometimes a trait seems to disappear in a family and then reappear in later generations. If neither parent has the trait, but some of the offspring do, what would you conclude about the inheritance of the trait?

Mark only one oval.

☐ Both parents are carriers of the recessive form of the gene.
☐ Only one parent has two copies of the recessive form of the gene.
☐ Only one of the parents has a dominant form of the gene.
☐ Only one parent has a copy of the recessive form of the gene.
☐ It is most likely the result of new mutations in each parent.

12. Cystic fibrosis in humans is caused by mutations in a single gene and is inherited as an autosomal (non-sex chromosome) recessive trait. A normal couple has two children. The first child has cystic fibrosis, and the second child is unaffected. What is the probability that the second child is a carrier (heterozygous) for the mutation that causes the disease?

Mark only one oval.

☐ 1/4
☐ 1/2
☐ 2/3
☐ 3/4
☐ 1
Human Heredity

Name ___________________________ Date __________

Human Characteristics

As you know, chromosomes work in pairs. The members of each chromosome pair are called homologous chromosomes, and the two chromosomes of each pair are approximately the same length, the same shape, and carry alleles for the same genes. Each chromosome of a pair comes from a different parent: one from the mother through the egg, and the other from the father through the sperm. Humans have 23 pairs of chromosomes, or a total of 46 chromosomes, per cell. Only 22 of these pairs are truly homologous. The twenty-third pair, the sex chromosomes, may or may not match, depending on whether the individual is female (XX) or male (XY).

The diagram below shows a generalized view of one pair of homologous chromosomes from a human. Assume the chromosome on the left is from the father and the one on the right is from the mother.

```
(from father)   (from mother)
F freckled     f unfreckled
T can taste    t cannot taste
B brown        b blond
h no disease   H has disease
Rh+            Rh-
M more         m less
c colorblind   C color vision
```

You should be aware that any two alleles of a gene have different effects on the trait that they control. For example, the M allele causes more melanin to be made in the skin, giving it a darker color. The m allele causes less melanin, resulting in a lighter skin color. Even though the effects are different, the two alleles in an allele pair control the same trait—in this case, skin color.

It is important to remember that just because a child inherits the recessive allele from a parent, that parent doesn't necessarily show the recessive phenotype. If the parent is heterozygous (one dominant allele and one recessive allele) they would show the dominant phenotype, not the recessive. In these cases, it is not always possible to know the phenotype of the parent.

In the problems below, you will use pipe cleaners and beads to model chromosomes, genes, and alleles. One pipe cleaner will represent the chromosome that is inherited from the father, and the other pipe cleaner will represent the chromosome inherited from the mother. Bead pairs will represent the genes, and bead color will represent the alleles. For each example, use the blue pipe cleaner to represent the father’s chromosome and a red pipe cleaner to represent the mother’s chromosome.
Human Heredity

Problem #1

Using pipe cleaners and beads, build the chromosome pair below. Use the chart on the last page to determine what color beads to use. Identify the genotypes and phenotypes of the person whose chromosomes are shown here and answer the questions.

<table>
<thead>
<tr>
<th>(from father)</th>
<th>(from mother)</th>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>t</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>b</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>h</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rh⁺</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which parent donated a blond hair allele?

Was that parent blond? Can you know for sure?

Is this person blond?

Is this person colorblind?

Can this person taste the chemical?

Is this person freckled?

Can you determine this person’s eye color or sex? Why or why not?
Problem #2

Using pipe cleaners and beads, build Kara’s chromosome pair below. Use the chart on the last page to determine what color beads to use. Identify the genotypes and phenotypes of Kara’s chromosomes shown here and answer the questions.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Was Kara’s father freckled? __________

Was Kara’s mother freckled? __________

Which of the two genotypes, FF or Ff would result in more freckles and why?

__________________________________________

Did either of Kara’s parents have the taste ability? ________________________________
Human Heredity

Problem #3

Using pipe cleaners and beads, build Juanita’s chromosome pair below. Use the chart on the last page to determine what color beads to use. Identify the genotypes and phenotypes of Juanita’s chromosomes shown here and answer the questions.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</table>

Juanita

Are all of Juanita’s brothers and sisters blond? Can you tell? __________

When Juanita has children of her own, will they have the taste ability? Why or why not? __________
Human Heredity

Problem #4

Using pipe cleaners and beads, build Phil’s chromosome pair below. Use the chart on the last page to determine what color beads to use. Identify the genotypes and phenotypes of Phil’s chromosomes shown here and answer the questions.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

What color is Phil’s hair? ______________

Is Phil’s skin color light or dark? ______________

Were both of Phil’s parents colorblind? Why or why not?

_________________________________________________________________
## Human Heredity

<table>
<thead>
<tr>
<th>Letter</th>
<th>Bead Color</th>
<th>Allele</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Bright Orange</td>
<td>Freckled</td>
<td>Presence of freckles</td>
</tr>
<tr>
<td>f</td>
<td>Peach</td>
<td>Un-freckled</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Hot Pink</td>
<td>Can taste</td>
<td>Chemical Taste</td>
</tr>
<tr>
<td>t</td>
<td>Light Pink</td>
<td>Cannot taste</td>
<td>Ability</td>
</tr>
<tr>
<td>B</td>
<td>Purple</td>
<td>Brown</td>
<td>Hair Color</td>
</tr>
<tr>
<td>b</td>
<td>Light Purple</td>
<td>Blond</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Green</td>
<td>Has disease</td>
<td>Presence of Disease</td>
</tr>
<tr>
<td>h</td>
<td>Light Green</td>
<td>No disease</td>
<td></td>
</tr>
<tr>
<td>Rh⁺</td>
<td>Dark Blue</td>
<td>Rh positive</td>
<td>Rh Blood Factor</td>
</tr>
<tr>
<td>Rh⁻</td>
<td>Light Blue</td>
<td>Rh negative</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Red</td>
<td>More melanin</td>
<td>Skin Color</td>
</tr>
<tr>
<td>m</td>
<td>Gray</td>
<td>Less melanin</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>White</td>
<td>Color vision</td>
<td>Color Perception</td>
</tr>
<tr>
<td>c</td>
<td>Black</td>
<td>Colorblind</td>
<td></td>
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</table>
Pigeon Genetics

Answer the following. Use information from Pigeon Breeding: Genetics at Work on the Learn.Genetics website to learn more about each inherited characteristic.

**Crest**

The crest characteristic in pigeons has two alleles: 'crest' and 'no crest'. 'crest' is recessive. Calculate the probability of the offspring of two heterozygous parents having a crest.

Using a Punnett Square:

Probability of offspring having a crest:

Using Math: Possible 'crest' alleles from father $\times$ possible 'crest' alleles from mother

$$2 \times 2 =$$
Crest

Explain how the following work together to give a pigeon a crest using the following words: 'crest' alleles, protein (for a bonus include: nucleotide and amino acid sequence):

Foot Feathering

The Slipper characteristic is partially dominant, meaning what we see is the product of both alleles that are inherited.

The 'No Grouse' characteristic is dominant.

Draw the foot feathering you’d see on a pigeon with the 'slipper', 'no slipper' and 'grouse', 'no grouse' genotype.

What is the genotype of the foot feathering seen here?
**Wing Pattern**
Wing pattern is determined by four alleles that follow a hierarchy of dominance.

The Pattern gene comes in 4 versions:

- 'T-check' allele
- 'Check' allele
- 'Bar' allele
- 'Barless' allele

**Wing Pattern**
Draw the correct phenotype for each genotype below.

<table>
<thead>
<tr>
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<tr>
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<td>[Image of pigeon with pattern]</td>
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Color
Color is determined mainly by one gene on the sex chromosome Z. This is known as ‘sex-linked.’ In addition, Color alleles have a hierarchy of dominance. In order of most to least dominant they are: ‘ash red,’ ‘blue,’ ‘brown’

Color
Calculate the probability of female offspring of the following cross NOT being red. Use a Punnett square or math.
**Spread**

Pigment distribution is determined by the Spread gene, the ‘spread’ allele being dominant to ‘no spread’. The ‘spread’ allele masks underlying wing pattern, which is known as epistasis. Circle the parental genotypes that could possibly produce the offspring shown:

Possible parental genotypes:
Recessive Red
The Recessive Red gene also determines feather color and is different from the Color gene. The recessive red characteristic is recessive (meaning two copies of the allele must be inherited) and epistatic to wing pattern.

Calculate the probability that offspring from the following cross will show a wing pattern. Circle the genotypes that would show a wing pattern.

The Recessive Red gene comes in 2 versions:

- “Not recessive red” allele (dominant)
- “Recessive red” allele (recessive)

Dilute
The Dilute gene also influences color, making some pigeons a lighter shade of their inherited feather color. The Dilute gene is sex-linked, residing on the Z chromosome and has two alleles: ‘dilute’ and ‘not dilute’. Calculate the probability of male offspring of the following cross being a lighter shade. Use a Punnett square or math.