A Study of Secondary School Students' Participation in a Novel Course on Genomic Principles and Practices

Adam Stefanile

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Abstract

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Since the inception of the Human Genome Project (HGP) there has, and continues to be, rapid changes in genomics, STEM, and human health. Advances, specifically in genomics, continue to be increasingly important as new knowledge in this field has led the trajectory for significant advancements in all biological disciplines. Throughout the scientific community there is an emphasis on increasing and improving genomic concepts and literacy for grades K-12. Numerous research studies report that there is generally a low level of genetic/genomic knowledge among the general public. The purpose of this research is to analyze and document evidence of secondary school students' participation, and educational outcomes, in a novel course on genomic principles and practices. A mixed methods approach, using qualitative and quantitative methods was used to address three research questions. 1) Based on affective evidence, how did secondary school students perceive and critically judge, content topics learned in a course on modern genomic principles and practices? 2) Based on cognitive evidence, how much of the content did secondary school students learn when they participated in a course on modern genomic principles and practices? 3) Using individual interview evidence, what are the major perceptions that the secondary school students expressed throughout the duration of the course? The results for Research Question 1 demonstrated that the students gained a significant level of new knowledge pertaining to genomics after attending the course sessions, based on their pre-and post-test Likert survey data. More particularly, they expressed more interest in, and understanding of genomic principles and practices. Concurrently, they became much more

critically reflective and evaluative about some of the societal and medical implications of its applications. With respect to Research Question 2, the secondary school students' content knowledge as measured by a 25-question multiple-choice pre-and-post test administered before and after the course demonstrated a significant increase. Lastly, the participants were provided an opportunity to comment on the course through individual and collaborative interviews, in order to find out to what extent they perceived the course to be interesting and challenging. Future inquiry expanding from this research would help to establish the foundational pathway for designing a more inclusive genomics curriculum.

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Adam Stefanile

Dedication

I am the first person in my immediate family to graduate from a doctoral program and the first to graduate from an Ivy league university. I would like to acknowledge my parents for assisting me financially and to look over the most important people in life: Angelica and Giovanni; while I was attending classes; my brother for discussing the intense and high level of caliber teaching; my sister who for her infinite support and encouragement. Finally, I would like to acknowledge and dedicate my research and thesis to the two most important people who are so special in my life: Angelica and Giovanni. There have been several times that the both of you have come to college with me. It was very enjoyable to see my children in an academic environment that differs from their school. There have been many times that I mentioned how happy I will be once I accomplish my final degree and graduate. Nothing in the world will ever make me prouder than to be your papa.

Chapter 1: Introduction

Background of the Study

Genomics is without a doubt one of the most groundbreaking scientific advances of the millennium, and scientists and science educators have endeavored to increase genomic education and awareness by highlighting a myriad of advancements in genomics, human health, and STEM (Collins & McKusick, 2001; Dougherty, 2009; Dressler et al., 2014; Haga et al., 2013; Hurle et al., 2013; McInerney, 2002). Moreover, genomic education, has the potential to impact students and society exponentially. While concern about the state of science education and STEM education in America has been well documented (Bybee, 2010), genomic education in the U.S. is unfortunately inadequate, in both quantity and quality (Crawford et al., 2018; Dougherty et al., 2011; Knippels, Waarlo, & Boersma, 2005; Kung & Gelbart, 2012; National Academy of Sciences, 2001).

The emergence of genomic research in the twentieth century has had a long and storied history of visionary research ideals in controversy on its merits and implications. In the early 1980s Renato Dulbecco was one of the first pioneers who researched the Human Genome Project (HGP) and supported the sequencing of human genomes to better understand cancer (Hood & Rowen, 2013). During that time (mid 1980s) the majority of biologists did not support the HGP, declaring that it was "bad science" and it was an arduous task that should be researched independently as opposed to collaboratively (Hood & Rowen, 2013). Many scientists also believed that the resources allocated towards the HGP would not justify the means (Collins, 1999; Cooke-Degan, 1994; Hood & Rowen, 2013; Service, 2001). "One of the key and distinctive objectives of the HGP has been the generation of large, publicly available, comprehensive sets of reagents and data (scientific resources or 'infrastructure') that, along with

other new, powerful technologies, comprise a toolkit for genomics-based research." (Collins, Green, Guttmacher & Guyer, 2003, p. 836) In fact, governmental agencies are consistently interconnecting and expanding their research in order to implement genomics into the public eye and mainstream media. These agencies include, but are not limited to, the following: Center for disease Control (CDC), Department of Energy's (DOE), National Human Genome Research Institute (NHGRI), National Center for Biotechnology Information (NCBI) and Food and Drug Administration (FDA); and educational institutions. Collins et al. (2003) emphasizes the importance of keeping the public informed about genomics, and the call has increased throughout the world. The future of genomics rests in the hands of our students; and the need to further establish genomics in high school curricula for the purpose of educating our future scientists is boundless (Collins et al., 2003; Molster et al. 2018; Venter & Cohen, 2014).

Genomics Defined

Genomics is generally referred to as the study of the content, structure, organization, and functioning of an organisms' genome. It is also concerned with the material contained in the genome that composes an organism and the analysis of multiple genes that interact with each other. However, *genetics* refers to the study of a singular gene of an organism. For over twenty years genomics has permeated many fields of science, and being that it is a relatively new and emerging field, it is an ideal discipline for designing and implementing it into an existing or new science curriculum.

Genomics, specifically, is a progressively emerging field throughout almost every domain in science. The development of innovative technologies and analytic tools associated with genomics has improved many aspects of human condition and has changed the way that science research is being conducted today. This includes, but is not limited to, medicine,

inheritance, pharmacology, diseases, forensics, reproduction, agriculture, and evolution. Sabatello et al. (2019) emphasizes:

> The ever-expanding prevalence of genetics in everyday life includes: ancestry testing; the increasing number of clinical genetic tests; the rise of research endeavors that utilize genome and exome sequencing, enroll pediatric participants, and offer families genetic results; and the professional opportunities in genomics that increasingly are available for adolescents as they train to enter the workforce (e.g., bioinformatics, genetic counseling). (p. 2)

These areas of research have, in turn, influenced ethical and social concerns, and stimulated the development of privacy laws and policies. There is overwhelming research supporting genomics education and how it is progressively expanding in the 21st century from a hands-on laboratory-based science (e.g., micropipetting and sample preparation) to a cutting-edge computerized database (e.g., GENBANK, (Basic Local Alignment Search Tool) BLAST, Medline; (Bigler and Hanegan, 2011; Kovarik et al., 2013; LaRue, McKernan, Bass & Wray, 2018; Maloney et al., 2010; Wefer & Sheppard, 2008). Now more than ever, genomics is reaching the mainstream media and well-known celebrities are using their public profiles to share their medical ideas and choices with genetic testing companies – such as: CRI Genetics, Ancestry DNA, 23 and me, and Family Tree DNA– and for good intentions, these companies have introduced, increased, and popularized genomics to a wide audience, both nationally and internationally. This is relatively important as a frontier in modern science and science education. Genetic testing companies provide the opportunity for the general public to become exposed to, and informed by, applications of modern genomic science. Over the last twenty years it has become increasingly common to read and watch news that is associated with genomic topics; and this requires society to be updated with scientific understandings and familiarity with modern principles, practices, and terminology in the field (Elmesky, 2013). However, it should be noted that quite often, popular entertainment and mainstream media quite often mendaciously

perpetuate incorrect genetic and genomic terminology to misinform the general public (Hurle et al., 2013).

Genomics in Secondary School Curricula

While acknowledging these advancements and benefits that genomics has on society (Collins et al., 2003; Lander, 1996; Wefer & Sheppard, 2008); there is very little attention to implementing genomics at the secondary school level (Kovarik et al., 2013; LaRue et al., 2018; McQueen et al., 2012) level despite the overwhelming educational and career benefits. One of the current problems across the nation as it relates to science education is the lack of implementation and integration of modern biological principles, specifically genomics, into the secondary school curriculum.

> High-school students will be both the users of genomic information and the genomics researchers of the future. Especially as they educate all sectors of society, high-school educators need information and materials about genomics and its implications for society, to use in their classrooms. (Collins et al., 2003, p. 7)

There have been national efforts from organizations such as the National Institute of Health (NIH), the American Society of Human Genetics (ASHG), NHGRI, Howard Hughes Medical Institute (HHMI), the Jackson Laboratory (JAX), and Cold Spring Harbor Labs/DNA Learning Center (CSHL/DNALC) to improve genomic and science education and genomic and scientific literacy at the secondary school level. “The level of science literacy of students in the United States, for instance, has been a source of concern to policymakers, educators, and citizens over the past decades, resulting in repeated calls and proposed strategies for raising students’ science proficiency” (Elmesky, 2013, p. 1156). Moreover, the physical resources are readily available and affordable for teachers and schools to adopt, and promote educationally, for student access, exposure, and learning. Modern biological and genomic topics such as: pharmacogenomics, genetically modified organisms (GMOs), Genome-Wide Association

Studies (GWAS), epigenomics, genome sequencing, and genome editing are easily accessible via genomic educational resources and interactive websites (Appendix B).

Recently, media sensation such as a television programming has focused on public access to genomic information from genetic testing companies including Ancestry DNA, Family Tree DNA, and 23 and me. This emphasis has with good intentions introduced, increased, and popularized genomics to a wide audience both nationally and internationally. These topics are rarely, if at all, taught in at the secondary school level (Dougherty et al., 2011; LaRue et al., 2018). While people may lack an overall understanding of how genomic information is extracted, extrapolated, sequenced, and analyzed for diagnosing a disease (Boerwinkel & Waarlo 2009; Bowling et al., 2008).

> Successful dissemination, understanding, adoption and adherence to genomic health recommendations will require an elevation of the genomic literacy of the public in the context of public health genomics– to promote the appropriate translation of the new science of genomics into health benefits to individuals and populations, and for evaluating the impact of genomic information on health care and disease prevention (Hurle et al., 2013).

Purpose

The purpose of this research is to document and analyze evidence of secondary school students' participation and educational outcomes in a novel STEM course on genomic principles and practices: *Introduction to Genomics.* One of the key guiding assumptions is by providing access and exposure to learning genomics the participants' level of content knowledge will increase in the fields of genomics, modern biology, human health, and STEM; and the expectation is that they will be better prepared to pursue career opportunities in genomics and/or STEM related fields. Since many schools throughout the nation, especially in New York City, do not focus on genomics or genomic careers and/or STEM career services, this research will provide a personal connection for underrepresented, urban secondary school students to engage

with, and develop a better understanding of, genomic principles and practices in a way that will more fully acclimate them toward these fields and encourage them to pursue the education necessary to participate in those careers. An essential question that was addressed in this research was: *What is a progressive method to teach genomics while enhancing a better understanding of biology for secondary school students?*

My hypothesis is that the participants will understand biology, human health, and STEM better and benefit from learning genomics being taught as a separate course by fostering a student-centered approach, and implementing interdisciplinary science learning and computer-based learning. In addition, I hypothesized that utilizing interactive websites (Appendix B) consistently would enhance the learning experience and inspire and encourage them to explore careers in genomics and/or STEM.

Given the novelty of this course, there was limited prior published research or information on how learning the principles and practices of genomics impacts secondary school students learning, whether its use in a STEM course enhances education. Thus, much of the theory and curriculum design was guided by more general learning theory and best classroom practices combined with judicious selection of genomic principles and practices that most likely would address secondary school students' interest, given the best evidence to date. Therefore, I used a survey instrument that was administered before and after the course to examine relationships between the use of Likert scale items and student knowledge and attitudes pertaining to genomics. Based on previous research of genomics education in secondary school settings (Bigler & Hanegan, 2011; Corn, Pittendrigh, & Orvis, 2004; Dawson, Carson, & Venville, 2010; Munn, O'Neill, Lane, Horsma, & Gregory, 1999), I further hypothesized that the

use of CBL, interdisciplinary science learning, and student-centered learning in a STEM class would improve knowledge and the learning experience for the participants.

This research aims to address the needs of secondary school biology students to make their biological education better grounded in, and informed by, modern advances in genomics; including relationships to human health principles and practices and career awareness in genomics and STEM. The goal is to document and analyze how the participants' engaged with and learned genomic principles and practices, and how to establish future research that will address the merits of learning genomics; and thus, promote a better understanding of biology, STEM, and human health, more broadly.

Research Questions

Research question 1: Based on affective evidence, how did secondary school students perceive and critically judge, content topics learned in a course on modern genomic principles and practices?

Research question 2: Based on cognitive evidence, how much did secondary school students learn when they participated in a course on modern genomic principles and practices?

Research question 3: Using individual interview evidence, what are the major perceptions that the secondary school students expressed throughout the duration of the course?

Organization of Thesis

Following this Chapter, Chapter 2 builds on this literature review to more fully explicate relevant prior published information relevant to the topics pursued in this research endeavor. Chapter 3 presents the methodology, which includes the academic setting, participants, strategies for developing and presenting the novel curriculum on genomics, and methods of data gathering and assessment. Chapter 4 is the Results of the study. Chapter 5 contains the Discussion.

Chapter 2: Literature Review

An extensive literature exists pertaining to the acquisition of genomic content knowledge and genomic learning, while developing a better understanding of biological and STEM principles and practices (Dressler, Jones, Markey, Byerly & Roberts, 2014; Hood & Rowen, 2013; Hurle et al., 2013; Sabatello, Chen, Sanderson, Chung, & Appelbaum, 2019). Increasing the level of content knowledge in these and other scientific disciplines further supports educating individuals in their personal and overall human health (Collins et al., 2003; Weber, Jensen & Johnson, 2015). Knowledge pertaining to genomic research, applications, and ethical, legal, and social implications (ELSI), may encourage a meaningful discourse and informed decision-making throughout the school community and eventually transform human health lifestyle, diet, exercise, pharmaceutical therapy, and decision making (Boerwinkel & Waarlo, 2009; Collins et al., 2003; Sabatello et al., 2019). Moreover, gaining familiarity with genomics may further dispel certain misconceptions pertaining to race, ethnic background, and human diversity (Yudell, Roberts, DeSalle, & Tishkoff, 2016).

Biology Curricula from a Historical Perspective

Traditionally, biology has been taught during the first year of secondary school, and is the most commonly offered course in the domain of science (Luckie et al., 2004; Maloney et al., 2010). This includes the teaching of other biological-related fields such as anatomy and physiology, forensics, and environmental science. The majority of schools worldwide implement some aspects of biology (e.g., living versus nonliving) into their classes during pre-kindergarten and kindergarten. It is at this age (4-5) that children first become exposed to biology (National Academy of Sciences (NAS), 1970). “The subject of biology grew out of a curriculum crisis” (Ladouceur, 2008, p. 447), and for the most part, the majority of less progressive biology classes

at the K-12 level “generally involves issuing a laboratory manual and charging the students with replicating a “science experiment” that thousands of other students have done before them.” (Luckie et al., 2004, p. 199)

From the perspective of curriculum (including level of content, and scope and sequence) secondary school biology classes throughout the United States are generally structured in the same manner, with pedagogy differing from teacher to teacher; and for the most part, biology and the mandated laboratory assignments are introduced with too much rote memorization and learning (Savage, 2016). Moreover, there is minimal engaged learning, student-centered learning, and CBL (Connell et al., 2016; Goodman, 2016; National Research Council (NRC), 1989; Southworth, Mokros, Dorsey, & Smith, 2010) interdisciplinary science learning, (Cvijovic et al., 2016; MacKinnon et al., 2013) learning modern biological principles and practices (Pevzner & Shamir, 2009), and addressing bioethical issues that are pragmatic to student-life (Chamany et al., 2018; Gess, 2017; NRC, 1989). According to the NRC (1989), “we are living in a Golden Age of Biology.” (p. 31) The advancements and discoveries in genomics continue to provide modern principles of biology and other domains in science with unifying themes connecting of subdisciplines (Connell et al., 2016; Cvijovic et al., 2016; Griffiths et al.,1999; Schatz, 2015; Woese, 2004).

Modernizing the biology curriculum. Research has shown that having secondary school students exposed to, and engaged in, learning modern and real-world science, associated to their lives creates an academic setting for students to become more interested in science (Alozie, Eklund, Rogat, & Krajcik, 2010; Holmlund, Lesseig, & Slavit, 2018; Kovarik et al., 2013; LaRue et al., 2018; NRC, 1989). Furthermore, it increases student comprehension (Bowling et al., 2008; Dougherty et al., 2011; Elmesky 2013) and promotes student awareness to

pursue careers in genomics and STEM (Dougherty, 2009; Haskell, (2015); LaRue et al., 2018; Mead, Hejmadi, & Hurst, 2017; Santschi et al., 2003). “It has been shown that high school teachers who introduce their students to careers and real-world issues increase student likelihood to enroll in STEM classes and pursue STEM majors in college” (LaRue et al., 2018, p. 48; as cited in Maltese and Tai, 2010). More importantly, there is a need for making biology instruction more up to date and authentic to reflect modern genomics and to make secondary school students scientifically literate citizenry (NRC, 1989).

In Dawson et al. (2010) the authors state that “it is essential that school science provides young people with the understanding and skills to become scientifically literate citizens in society.” (p. 38) In addition to making our students scientifically literate citizens, secondary school students are the first to transition into becoming pre-college students, who will eventually enter sciences, All of this is with the hope of preparing this generation and future ones to be aware of the promises and challenges of the genetic revolution that genomics research and applications present (Collins et al., 2003; Pevzner & Shamir, 2009; Willingale-Theune et al., 2009).

Numerous studies continue to support genomic education for secondary school students, as this group can serve as a “domino effect” primarily because they (the students) will transmit new information to their parents, and in turn subsequent generations will transform this information (genomics) to improve their lives as well as their understanding of genomics (Collins et al., 2003; Dougherty, 2009; Dressler et al., 2014; Verhoeff, Jan Boerwinkel, & Jan Waarlo, 2009). Recent studies indicate that the general public, and more importantly, secondary school students, have a relatively low level to no knowledge of modern biology and genomic principles (Bowling, 2008; Carver, Castéra, Gericke, Evangelista, and El-Hani, 2017; Condit,

2010; Dougherty, 2011; Knippels et al., 2005; Lewis & Wood-Robinson, 2000; Miller, 2004). Despite the ubiquity of genomics in modern society and everyday life, there is a halt to implementing, and/or merging, the principles of genomics into biology or health curriculum.

Bioinformatics. Advances in computer technology continue to improve all domains of science research and development, from molecular biology to bioinformatics. Bioinformatics is an interdisciplinary field that combines all components of STEM. NHGRI defines bioinformatics as "a subdiscipline of biology and computer science concerned with the acquisition, storage, analysis, and dissemination of biological data, most often DNA and amino acid sequences. Bioinformatics uses computer programs for a variety of applications." As students acquire a conceptual basis of modern biology, genomics, and bioinformatics, they will develop interdisciplinary skills and strategies while integrating their knowledge of extrapolating and analyzing genomic data in a real-world context (Ditty et al., 2010; Kovarik et al., 2013). This type of learning will benefit greater society by addressing and solving real-world problems related to science and human health (Bybee, 2010; Gess, 2017; Venter & Cohen, 2014). "There is no sign that the demand for bioinformatics specialists is abating. Indeed, the demand will continue to grow rapidly, given estimates that as many as 40% of the biotechnology companies that survive will be selling information rather than products" (NRC, 2001, p. 328, as cited in Kovarik et al., 2013).

Prior Research in Genomic Education

Sabatello, Chen, Sanderson, Chung, & Appelbaum, (2019) elaborated on the lack of implementation among many secondary schools to include genetic concepts that affect everyday life as well as providing secondary school students and science teachers with the resources that are widely available. In their study, they assessed and compared two pathways (video versus

pamphlet), that were randomly selected for educating secondary school students with genome sequencing. The goal was to evaluate the effectiveness of the two pathways. Students had prior genetic/genomic content knowledge and were a given a pre-and-post survey of genomics knowledge and the benefits and challenges of genomic sequencing. Their study concluded that most of the students benefitted from both pathways and expressed an interest in participating in genomic research.

Tanner (2013) highlighted pedagogical strategies for biology teachers that have been successful in teaching of biology and can be easily utilized in a genomics class. These pedagogical strategies have been used to support student learning and cultivate classroom equity at the undergraduate level including:

- "Giving students opportunities to think and talk about biology
- Encouraging, demanding, and actively managing the participation of all students
- Building an inclusive and fair classroom community for all students
- Monitoring behavior to cultivate divergent biological thinking
- Teaching all of the students in your biology classroom" (p. 322).

Tanner (2013) emphasizes the strategies listed above as an introductory point for science educators to improve on establishing an equitable classroom environment for student engagement with learning biology.

The research of Gallagher et al. (2011) reported success with designing and implementing a curriculum for computational biology into advanced secondary school biology classrooms. The curriculum included an introduction to the models of algorithms, an overview of the BLAST algorithm used to compare DNA sequences, and methods for building phylogenetic trees. Students conceptualized the benefits and pragmatics as to why biologists should have a fundamental understanding of how computational tools are related to scientific research for modernizing human health.

Kovarik et al. (2013) introduced a bioinformatics curriculum led by the Northwest Association for Biomedical Research (NWABR), for science teachers through a professional development program aimed to use bioinformatics tools to educate high school students in genetics and other STEM disciplines (biology, molecular biology, bioethics, and evolution) and STEM careers. One of the benefits of professional development was how teachers transformed DNA concepts into hands-on DNA barcoding and used the polymerase chain reaction (PCR) process for student learning. These newly acquired concepts inspired students to explore real-world problems and incorporate authentic science learning as an effective approach to increase awareness in modern genetics. For example, students used interactive web-based learning to investigate certain genetic diseases such as breast cancer susceptibility1 (BRCA1) gene using BLAST and visual molecular images to conceptualize the effect of gene mutations.

Genomic Education

Research has shown that the majority of secondary school students are introduced to only a small percentage of genomic concepts such as monogenetic/Mendelian traits as opposed to polygenetic diseases, which are more common and life threating (Dougherty et al., 2011; Hussain, 2015; LaRue et al., 2018). The advancement in many aspects of genomic education has personalized, and continues to personalize, genomic principles and practices to provide a "practical learning opportunity for students to not just discuss genetics and genomes in abstract, but to learn in a more active and relevant way as they analyzed their own personal genomics data." (Weber et al., 2015, p. 14) The level of complexity with genomics can be modified to incorporate themes and concepts for the purpose of teaching it in the class since; "many genomic concepts are well within the capabilities and scope of general secondary school biology education." (LaRue, et al., 2018, p. 48)

According to McInerney (2002):

> genomic education needs to be revolutionized by emphasizing human variation and individuality at its core: Unfortunately, the centrality of individual variation in genetics has been obscured for the public by a focus on single-gene disorders in the high school biology curriculum, the only formal exposure to genetics for most people, and by deterministic treatments of molecular biology by scientists and media alike. (p. 373)

Efforts have been underway to increase genomic education and awareness to all individuals in the fields of science education and health (Boerwinkel & Waarlo, 2009; Kovarik et al., 2013). This includes, but is not limited to, teachers, scientists, physicians, researchers, nurses, physician assistants, pharmacists, nurse practitioners, and other health professionals. Francis Collins, former Director of NIH, describes the pragmatic applications, trajectory, and the future of genomics.

> By the year 2020, gene-based designer drugs are likely to be available for conditions like diabetes, Alzheimer's disease, hypertension, and many other disorders. Cancer treatment will precisely target the molecular fingerprints of particular tumors, genetic information will be used routinely to give patients more appropriate drug therapy, and the diagnosis and treatment of mental illness will be transformed (Collins, 2001).

The majority of collegiate institutions, scientific and medical organizations, and the scientific community want to prepare and integrate secondary school students for learning modern principles and applications of science; it should, be essential that learning genomics should be an integral component of the secondary school curriculum (Collins et al., 2003; Verhoeff et al., 2009). The discoveries and advancements in genomic research have allowed scientists to improve their research on the complex biological concepts and processes pertaining to aspects such as: hereditary factors with traits and diseases; human evolution and variation, and structure and function of genes and proteins (Collins et al., 2003). These concepts as well as other genomic concepts should be gradually implemented into all secondary school science curriculums, primarily because K-12 and secondary school science teachers have, to some

degree, an impact on increasing student comprehension, literacy, knowledge, engagement, and informing the general school community. Genomics also offers both teachers and students an opportunity to engage in research and collaborate with some supporting organizations (as previously mentioned) and provides an opportunity for developing and designing research which involves cognitive capabilities (Campbell, 2003; Elmesky 2013; Tomlinson, 2005). “Teachers can establish a learning environment that fosters student construction of knowledge in different age groups, achievement levels, and content areas, such as genetics.” (Alozie et al., 2010, p. 225)

One of the factors contributing to the focus of genomics and K-12 education is the lack of teacher training, education, and professional development (Kennedy, 2016) that exists nationally among K-12 science teachers despite the overwhelming on-line resources (Appendix B), informal learning, and outreach programs (R. DeSalle, personal communication, June 4, 2015); Dougherty, 2016; (C. Wray, personal communication, June 28, 2018). Science teachers, who are not well-versed in genomics/genetics and/or who may have similar misconceptions of genomics/genetics as their students, “have limited opportunity to update their skills and little access to genomic science curriculum materials that can be used to improve learning in all students.” (Hurel et al., 2013, p. 5)

Genomics and biology. The concept of teaching the same biology topics (as previously mentioned) over the course of one academic school year has existed for over 100 years (Ladouceur, 2008). Many K-12 schools provide miniscule opportunities for students to learn about genomic topics that are directly associated with biological principles (structure and function of DNA, chromosome structure, biological diversity, diseases) and processes (fertilization, mitosis, meiosis, evolution, transcription, and translation). These are all major components of the biology curriculum that all too often are given small emphasis, if at all.

Within the last decade, genomic concepts including: bioinformatics, DNA extraction, chromatography, and gel electrophoresis have been emerging in the laboratory setting of biology classes (Bigler & Hanegan, 2011; LaRue et al., 2018; Savage, 2016). The National Science Education Standards (NSES) provides the guidelines for K-12 science education in the United States; particularly, the science content standards that indicate the level of genomic and related concepts that K-12 students should learn (Hollweg & Hill, 2003). (Appendix E).

Science teachers can consistently integrate these and other genomic concepts, processes, and phenomena into their curricula at a specific level of understanding that is not too complex, in order for students to acquire a coherent understanding of genomic principles and practices (Alozie et al., 2010; Kovarik et al., 2013; Tanner, 2013. By the time secondary school students graduate, they should be exposed to a broad level of genomics education and better prepared for undergraduate science courses.

Integrating genomics and biology. Integrating and promoting genomics into an existing biology curriculum encourages schools and teachers to modernize their curriculum (Kovarik et al., 2013; Nagle, 2013), laboratory assignments, and lessons in order for students to be up-to-date with modern scientific principles and practices (Hood & Rowen, 2013; Lander, 1996). The use and implementation of technology can assist science teachers with developing and designing unique learning opportunities (Okita et al., 2013); and by utilizing interactive websites (Appendix B) science teachers can become proficient with these websites (through professional development) and integrate a CBL pedagogical framework into their curriculum repertoire. Moreover, interactive websites can be used without any budgetary constraints. As described by Southworth et. al (2010), teachers who are implementing technology and genomics into their curriculum experience great success using three (3) strategies: “they prompt discussion at critical

junctures, promote pair and small-group work, and encourage the use of data-based evidence." (p. 3). In fact, many students in varying grade and academic levels "are eager to learn about genomics and its impact. Faculty are quickly learning to incorporate various aspects of genomics into their curriculum, either by developing new genomics courses or by incorporating bits and pieces of data into existing courses." (Campbell, 2003, p. 98)

Pragmatics of Teaching Genomics

Ambitious science teachers who are interested in advancing their knowledge and curriculum with modern scientific and genomic concepts can implement many aspects of genomics into an existing biology, health, and STEM curriculum (Collins et al., 2003; Corn et al., 2004; 2016; Maloney et al., 2010). This does not necessarily mean that the conceptual structure of an existing curriculum needs to drastically modified or replaced (Boerwinkel & Waarlo, 2009). Some of the topics in the biology curriculum are disconnected from students' lives (van Eijck & Roth, 2007); however, there are pragmatic topics in the mainstream media that encourage students to be proactive with their learning while conceptualizing genomic concepts that are directly related to their personal life and the future of society (locally, nationally, and internationally). These pragmatic topics include: genetically modified organisms (GMOs), chromosomal abnormalities, diseases, ELSI, prevention-based medicine, DNA barcoding, cloning, and other topics (as previously mentioned. Many of these topics are inspiring and empowering for students to learn (Dressler et al., 2014; Wefer & Sheppard, 2008) in order to establish the proper education necessary to participate in a scientific career.

Practical benefits of genomics and society. Thanks to the scientific advancements in understanding DNA, scientists are better equipped to understand the significance genomics has with: comparative genomes of different species, the probability of acquiring genomic

diseases/disorders, human evolution, the effects of environmental factors (non-genetic) and gene interaction and human health (Collins et al., 2003). Integrating STEM and genomics has advanced strategies to engineer ways to identify harmful pathogens such as antibiotic resistant pathogens including Staphylococcus aureus (MRSA), develop personalized medicine, improve the treatment of oncological diseases (Haspel & Saffitz, 2014), and establish laws Genetic Information Nondiscrimination Act (GINA). Genomics consistently transforms the way medicine, nature, education, and research affect human health (Hood & Rowen, 2013).

The Lack of Inclusion of Genomics in the Curriculum

Within the field of science education, researchers have described that science administrators, curriculum developers, and a number of science teachers are not preparing secondary school students for learning genomics (Dougherty et al., 2011; Dressler et al., 2014; Munn et al., 1999) that is sufficient for modern biological and human health concepts, and STEM and encourage them to become future scientists. This is a growing concern for scientists and educators in the scientific community that of which, have the proclivity to guide secondary school students who wish to pursue careers in genomics and/or STEM and anticipate them in becoming future scientists for the next generation. “Students today are coming of age in the genomics era and they will play an important role in shaping future ethical, medical, legal, and privacy issues related to how genetic information is viewed and used.” (Weber et al., 2015, p. 14) The lack of access and exposure among secondary schools and outreach programs is a continuous theme that has been extensively documented in *Public Library of Science* (PLOS) (Cvijovic et al., 2016; Dougherty, 2009; Lewis, 2016; McQueen et al., 2012; Santschi et al., 2013). Additionally, there is a substantial emphasis with educating secondary school students with monogenetic/Mendelian traits, and this is contributing “to persistent student conceptual

difficulties, including genetic determinism (one gene, one trait; lack of emphasis on environmental influences or polygenic traits) and confusion about the nature of genetic material and the genetic basis of disease." (Ruegg, 2017, p. 3, as cited in Bowling, 2008; Shaw, 2008; Smith, 2008).

Science teachers allocate too much time conveying genetics accurately, and at times results in misunderstandings, such as most traits and diseases are inherited in a "simple" manner. There is a rationale for a paradigm shift from teaching monogenetic inheritance and diseases to polygenic inheritance and diseases for the sake of conveying both pragmatic and contemporary aspects of genomics to students (Dougherty et al., 2011).

Moreover, Dawson et al. (2010) argue that teachers continue to place emphasis on educating their students with monogenetic diseases as opposed to polygenetic/complex diseases, which is more prevalent among teenagers who suffer from asthma, diabetes, or celiac disease. Some of these challenges are being met by emerging new teaching materials that address these issues. *Genetics Education in the 21st Century* is a project that focuses on curriculum materials that address students who suffer from polygenetic diseases and provides them the opportunity to teach and inform themselves about their genetic health condition. This approach provides the student with meaningful and pragmatic information to make decisions using genetic facts and details related to their well-being. In this program, students have the autonomy to conduct their own research on how to develop and improve their lifestyle while collaborating with other students with similar conditions.

Addressing these educational gaps may seem difficult, given the fact that many "state-mandated curricula do not include many contemporary genomics concepts, but it can be facilitated by developing educational materials that can be widely and freely disseminated that

high school students can explore independently or that teachers can easily incorporate into classrooms discussions." (Sabatello et al., 2019, p. 3) In further support of modernizing the science curriculum to include genomics, modern science, and STEM, Maloney et al. (2010) state:

> No science curriculum can remain current without a bioinformatics component. Projects such as the sequencing of the human genome have changed the nature of instruction. A modern biology course must address new techniques in gene mapping. Students need to understand what bioinformatics-related computer software programs do and how they do it. (p. 173)

Why is Genomics Not Implemented in Secondary Schools?

One of the major reasons that genomics has not been integrated in most secondary school science classrooms is due to a lack of professional development (Dougherty et al., 2011; Holmlund et al., 2018; Kennedy, 2016; Kovarik et al., 2013; LaRue et al., 2018) and teachers' lack of content knowledge (Haga et al., 2013). Many highly effective and educated science teachers have limited genomic and modern human health content knowledge. Moreover, the slow rate of some states to integrate genomics and modern human health concepts into the science curriculum does not provide science teachers with incentives or passion to integrate modern scientific principles into their pedagogy or lessons (Hurle et al., 2013; LaRue et al., 2018). In further support of this finding, Machluf and Yarden (2013) address the need for secondary school educators to update their students understanding of genomics, bioinformatics, and other contemporary fields of biology in order to avoid the continuation of "lagging behind cutting-edge scientific discoveries, which hold great potential for supporting students' understanding and eliciting their interest and motivation to learn science." (p. 648)

According to Carver et al. (2017)

> Students in high school find genetics particularly challenging to learn because it requires reasoning across multiple organizational levels: between genes, proteins, cells, tissues,

> and organs. Students find it difficult to understand how mechanisms and interactions at the molecular (genes, proteins) and micro-levels (cells) bring about effects at the macro-level (organism, population). Moreover, they find it difficult to understand the mechanisms of gene expression, and how environmental factors interact with genes. Within public health, genetic determinism is thought to have a negative impact on people's understanding of health and disease. (p. 5)

Rationale for Teaching Secondary School Genomics

Duncan, Rogat, & Yarden (2009) have noted that most students currently fail to develop a deep understanding of fundamental ideas in modern genetics by the end of compulsory education. Genomics has become increasingly relevant to peoples' lives, with news and information pertaining to human health and society (Dougherty et al., 2011; Lander, 1996; LaRue et al., 2018; McInerney, 2002). Moreover, Kung & Gelbart (2012) reminded us that technology races ahead, and there is a critical educational need to prepare the public for the increasing accessibility of genetic information. Students who have not experienced, nor who have had any access to learn, genomics will have multiple opportunities to independently and collaboratively work with "big data" of bioinformatics databases to better understand the nature of science, science investigation, and authentic interdisciplinary science learning (Kovarik et al., 2013; Maloney et al., 2010; Wefer & Sheppard, 2008; Williams & Teal, 2017). Once students conceptualize, for example, monogenetic diseases and polygenetic diseases, they will develop and increase their understanding how the environmental and their individual lifestyle interact with their genomes and ultimately may affect their overall health (Bowling et al., 2008; Dougherty et al., 2011; Hussain, 2015; McInerney, 2002; Novarik et al., 2013). Genomics is an interdisciplinary science and offers excellent opportunities for emphasizing interdisciplinary science learning associated with genomics and STEM education (Boerwinkel & Waarlo, 2009; Dymond et al., 2009).

Interdisciplinary Science Learning

As students acquire a conceptual basis of genomics, they will develop interdisciplinary skills and strategies while integrating their knowledge in a real-world context (Holmlund et al., 2018; Marioni et al., 2016; Nagle, 2013; Tripp & Shortlidge, 2019; U.S. Department of Education, 2016). Studies have shown that students who develop interdisciplinary skills and strategies familiarized themselves with innovative learning, design process, sharing educational and technological resources, collaborating with industry, and research (Allen, 2017; Frank & Barzilai, 2004; Nagle, 2013; Szostak, 2013). Although interdisciplinary science learning has not fully emerged throughout many science classrooms, a number of organizations are supporting and collaborating with educators and students to establish a framework for interdisciplinary science learning (Nagle, 2013; Tripp & Shortlidge, 2019). "Development and implementation of genuinely interdisciplinary undergraduate courses and curricula will both prepare students for careers as new biology researchers and educate a new generation of science teachers who will be well versed in new biology approaches." (Labov, Reid, & Yamamoto, 2010, p. 14)

Dymond et al., (2009) supports technology learning to emphasize genomics and interdisciplinary topics (STEM) as opposed to traditional biology courses, which focus on memorization-based learning.

A more general perspective on interdisciplinary learning. The term "interdisciplinary" has been defined as a process of incorporating multiple disciplines with the intention of developing new ideas, make connections, explain a phenomenon, or solve a problem, that would be unlikely through a single disciplinary means (Borrego & Newswander, 2010; Nagle, 2013; Repko & Szostak, 2020; Tripp & Shortlidge, 2019). This perspective began to emerge in the early 20th century for the purpose of integrating two or more contrasting

disciplines to inspire individuals to cultivate themselves in learning science, more thoroughly apply it to their interests, and make it relevant to their lives (Nagle, 2013; Tripp & Shortlidge, 2019). This is a very common practice that is emerging in STEM education and practices. Exposing students in K-12 and undergraduate courses "to a more interdisciplinary curriculum will help them to better collaborate with their scientific peers in other disciplines as well as design more interdisciplinary projects on their own." (Tripp & Shortlidge, 2019, p. 4, as cited in the National Research Council (NRC), 2003).

Tripp and Shortlidge, (2019) suggest STEM curricula should integrate STEM and non-STEM to address real-world challenges that affect society, public policy, the economy, and other social sciences. The authors noted that, consequently, these students are "more receptivity to new ideas, are more sensitive to ethical issues due to the exposure of non-STEM perspective.

The research of Borrego and Newswander (2010) combined practical knowledge from interdisciplinary learning in the fields of engineering and humanities to provide an advance understanding of the research methods in a natural and laboratory-based setting and provide constructive suggestions for the outcomes of interdisciplinary graduate education.

Computer-Based Learning

In this research study, computer-based learning (CBL) takes a prominent role in the design of the genomics lessons. Some relevant prior research is reviewed. Clarke (2001) lists multiple pedagogical strategies associated with computer-based learning (CBL) that can increase and develop student learning, scientific interests, and other practicalities associated with their personal lives and careers. The principal types of CBL includes:

- Computer-based training (CBT)
- Computer-managed learning (CML) or managed learning environments (MLE)
- Integrated learning systems (ILS)
- Intelligent tutoring systems (ITS)

- Job aids or electronic performance support system (EPSS)
- Computer-aided assessment (CAA)
- Drill and practice
- Virtual reality (VR)
- Multimedia
- Hypermedia
- Online learning
- Resource-based learning
- Simulation.

Clarke (2001) states how all of these different approaches have been successfully used to deliver quality learning experiences on their own. However, in many cases they have been combined to bring together the advantages of several types of CBL so that:

- The richness of hypermedia can be added to CBT
- Assessment can be added to all the approaches
- Materials can be delivered online
- Simulation can be used to extend a computer-based tutorial
- Multimedia can be used to help motivate learners being assessed.

There are numerous interactive and informative genomic/genetic websites and on-line scientific resources (Appendix B) that are reputable to implement into a genomics curriculum, while incorporating a technology-based framework. Using a particular CBL module or multiple, CBL strategies (some mentioned above), secondary school students will have access and exposure to modern biological advances, interactive technologies, and scientific research within their classrooms. Using reputable websites (Appendix B) has the potential to increase student motivation in the scientific subject and enhance student learning by making the topic more relevant and personal.

As described by McQueen, Wright, and Fox (2012):

> Genomics technologies and bioinformatics analyses have changed the way that biological research is being carried out today. Given the rapid pace of advancements in these fields, the development of science-literate citizens can be greatly aided by introducing current scientific breakthroughs and technologies early in high school curricula. Genomics is an ideally suited subject area for designing and implementing high school education

> initiatives because of its broad relevance to many fields of cutting-edge research, the ability to engage students with freely available online tools, as well as the availability of a growing number of teaching and curricula resources. (p. 1)

Why is CBL effective for learning? Having access to the wide range of web-based digital learning applications (Appendix B) can make learning more engaging, interactive, effective, and less boring. Computer visualizations help to simplify complex principles and processes in science (Sabatello et al., 2019) and is ideal for educating any grade level student. Palincsar and Ladewski (2005) advocate for CBL due to the fact that "computers and media as tools for learning due to the fact that it is increasingly central to the lives of today's children and youth; global popular media culture, including online culture, have become integrally bound up with children's and youth's affiliations, identities, and pleasures," (p. 308) CBL is highly effective, relevant, and useful for secondary school students who regularly use the Internet, social media, and apps and who frequently have smart phones (Sabatello et al., 2019).

Curriculum

Curriculum is associated with external and internal factors within the learning situation. Externally, curriculum is correlated with the social and educational framework of the scientific community, in regards to genomics, which then, develops into a program that is supported by the school community that deems the curriculum suitable for classrooms. Internally, the curriculum serves as a procedural process for teachers to organize their scope and sequence of the content. Curriculum can be viewed as a tool for making social connections between the public (societal) interest in education and student achievement and expectations (Doyle, 1992). A possible challenge for curriculum developers is to provide content that is connected to students' lives and interests, as many students feel that their current science curriculum is not associated with their lives and interests; and this misalignment stems from a lack of student involvement with

decision-making and life-relevant teaching content of the curriculum (Hagay & Baram-Tsabari, 2015). Furthermore, science teachers generally have autonomy towards choosing a curriculum and its relevancy for the classroom and the interests of the student. Students at times, may reject the teacher's choice and do not become engaged in science; which then, under the worse circumstances, can lead to boredom in the classroom (Eisenhart, Finkel & Marion, 1996).

Developing a genomics curriculum for secondary school students. Historically, genetics has been minimally taught at the middle school level, or taught as part of a biological unit at the high school level (Dawson et al., 2010) and more typically taught in depth and as an elective course at the college level. The biology units usually encompass cells, chromosomes, genes, and alleles, dominant and recessive factors, genetic probability, independent assortment, gene segregation, and monogenetic diseases. Currently, on a smaller scale, some universities and institutions have developed a genomics curriculum and has been implemented to doctoral students, biology majors, pre-and- post-medical students, physicians, nurses, and pharmacists (Banta et al. 2012; Ditty et al., 2010). This supports my research involving a gap that currently exists in genomic education at the secondary school level, which, has been identified and acknowledged by personal interviews conducted with numerous scientists at AMNH, the Jackson Laboratory, and the National Institute of Health (NIH); and science educators at ASHG and Teachers College, Columbia University. Hurle et al. (2013) emphasizes how "acquiring adequate genomic science education in K-12 is needed as a means to increase long-term genomic health literacy in our society.

As mentioned throughout this paper, monogenetic diseases (a change in the DNA sequence causing a defect to one specific gene of an individual's genome) exists in the curriculum of the majority of secondary schools and institutions. However, polygenetic/complex

diseases, (multiple defective genes) and other topics mentioned throughout this paper, do not exist in the curriculum of many secondary schools throughout the nation. Scientists argue that secondary schools and institutions that fail to implement polygenetic/complex diseases into their curriculum have failed to provide adequate education for our 21st century classrooms, Dougherty (2009). This may or may not be a valid point for developing a genomics curriculum. However, the fact of the matter is the United States continues to lag at the high school level in general science, biology and genomics when compared with other countries; for example, England, Germany, Netherlands, and Israel. If schools, health institutions, private organizations, and society want to prepare high school students for the future and science educators want to prepare their students to become future scientists, then genomics should be an integral component of the high school curriculum (Verhoeff et al., 2009).

LaRue et al. (2018) highlight three topical components that secondary school science teachers should emphasize in their classrooms as it relates to genomics, STEM, human health, and modernizing biology: *Molecular genetics, bioinformatics,* and *bioethics*. These three topical components, along with other genomic components including, but not limited to, the human microbiome (HMB) Plotnikoff & Riley, 2014; Waldor et al., 2015), GWAS, (Marioni et al., 2016), ELSI, (Kung & Gelbart, 2012), and careers in genomics and STEM (Kovarik et al., 2013; LaRue et al., 2018; Stark, 2011), are quintessential for designing a genomics curriculum for any and all secondary school science classroom (Bigler & Hanegan, 2011; Gallagher et al., 2011; Kung & Gelbart, 2012).

Borland (2000) suggests developing "basic skills in reading, writing, and mathematics; problem-solving skills; and positive school attitudes and behaviors." (p. 16); in order for secondary school students to become proficient in both genomics and STEM. Borland's (2000)

Project Synergy was a gifted program established for elementary school children in Manhattan, NY; and although there is a difference in age with this current research as compared to Borland's research, the overall goals are fundamental for initiating a genomics course. In developing the course, I included specific aspects as stated by Borland (2000):

> Develop nontraditional ways to identify young, economically disadvantaged, potentially gifted students; (b) to work with identified children, their parents or guardians, and their teachers to encourage the develop- mention of the children's potential for academic giftedness; and (c) to secure appropriate academic placements for identified children. (p16)

Tomlinson's (2005) research on curriculum and instruction for highly motivated and gifted students involved seven features for an effective curriculum and instruction:

1. Allowing students to conceptualize facts and details rather than rote information while developing their attitudes and thoughts towards a specific topic. This "directs students' attention to rich and profound ideas, and ensures grounding in what matters most in each topic and discipline." (p. 161)

2. Provide students with resourceful interdisciplinary skills to guide "students in understanding where, how, and why to use what they learn." (p. 161)

3. "Engages the students affectively and cognitively. Students find pleasure, or at least satisfaction in what and how they learn." (p. 161)

4. Differentiate instruction and pacing.

5. Transform rather than transmit learned content knowledge "to solve problems, address issues, and create products that are meaningful and purposeful" (p. 161) for secondary school students.

6. Guide students to become independent and collaborative thinkers.

7. Practical and applicable to a students' life which includes "gender, culture, economic status and exceptionality." (p. 161)

Teaching and Learning Genomics in Secondary School

The need to integrate genomics into secondary school science classes has been supported by scientists, science educators, and science researchers nationally and internationally. Verhoeff et al. (2009) have emphasized that modern science has made so many great advances that the

quantity of ‘basic' science to be taught in the classroom increases year on year in an increasingly encyclopedic way. Only recently has genomics been introduced to middle and secondary school students informally through outreach programs and exhibitions at the Smithsonian Institution, Howard Hughes Medical Institute (HHMI), American Museum of Natural History (AMNH), and Cold Spring Harbor; in an effort to encourage and educate both students and the general public.

> Most major universities, research institutions, and museums provide some sort of science outreach. Their aims are varied. They help improve science education in middle and high schools. They encourage more students to pursue careers as researchers. They work to increase science literacy among voters and legislators. And they aim to communicate the wonder and the joy of science to the world at large. Science outreach isn’t just an add-on, say the people involved in doing it, it’s an essential part of doing science. (Savage, 2016, p. 1085)

According to Munn et al. (1999), it is important to note that education in genome science is needed at all levels in our society by specific audience and the general public so that individuals can make well-informed decisions related to public policy and issues such as genetic testing. Research has shown that the majority of secondary school students are introduced to only a small percentage of genetic concepts such as single Mendelian traits, genetic cellular processes: transcription and translation, genetic diseases, and inheritance. These concepts are often taught from an outdated biology textbook that is more than 1000 pages long, and has an abundance of topics that are, to some extent, disconnected from the lives of secondary school students. Few secondary school biology textbooks mention the term or subdivisions of genomics, and like the vast majority of modern science principles that are taught at the secondary and undergraduate level, instruction relies on the use of modern science textbooks (NRC, 1989). Moreover, Sabatello et al. (2019) remind us that current studies indicate that high school biology textbooks are deficient in their explanations of key issues, such as gene-environment interactions. Additionally, science teachers who are mandated to provide students with genetic content

knowledge often confuse students by navigating from one chapter of the book to another and frequently neglect to interrelate concepts that are involved with other aspects of biology including: molecular, population, ecology (Knippels et al., 2005).

Liu, as cited by Savage (2016), states that the standard biology textbooks are "basically encyclopedias of what we know. They're very little concerned with how we know it." (p. 1086) Many science textbooks are

> Dismembered collection of facts and thoughts and snippets, and that's not how science is done. Instead of a dry list of facts, science is a process of people struggling to understand some phenomenon, sometimes failing, and then coming up with a new line of attack. Talking about it that way can help pro- mote people's appreciation of science, and get what they hear to stick in their minds. (Savage, 2016, p. 1085)

Dymond (2009) describes how genomics and STEM and careers associated with STEM have entered into the genomic era, and science educators are having difficulty addressing genomic concepts at the college students due to the lack of exposure at the secondary school level.

As described by McQueen, Wright, and Fox (2012),

> Given the rapid pace of advancements in these fields, the development of science-literate citizens can be greatly aided by introducing current scientific breakthroughs and technologies early in high school curricula. Genomics is an ideally suited subject area for designing and implementing high school education initiatives because of its broad relevance to many fields of cutting-edge research, the ability to engage students with freely available online tools, as well as the availability of a growing number of teaching and curricula resources. (p. 1)

Kung and Gelbart (2012) describe a vision for genomic education at the secondary school level addressing literacy and genetic educational resources:

> The current generation of high school students will be the first to come of age in the era of personal genomics, making choices that will determine how personal genetic information is incorporated into society. Targeting educational efforts toward the existing infrastructure of high schools offers a broad and cost-effective approach to ensure that the majority of this generation has been exposed to key genetic concepts and has had the

> opportunity to discuss and de- bate the benefits and risks of personal genetics for individuals and society. (p. 90)

Genomic Literacy

Over the past twenty years, modern science curricula have consistently moved toward more authentic and progressive science learning that emphasizes the principles and practices of science and science literacy (Labouta et al., 2018; Kastens et al., 2017). This is also consistent with the widely accepted goals of the Next Generation of Science Standards (NGSS Lead States, 2013). Historically, the origins of these movements have been rooted in the reforms following Sputnik (Rudolph, 2012; Bybee, 2007). One significant challenge across the nation is the lack of "genomic literacy" that currently exists at the secondary school level despite the overwhelming advances in genomics that continue to emerge throughout the scientific community. Genomic literacy refers to sufficient knowledge and understanding of genomic principles and practices to make informed decisions about one's personal well-being and the ELSI associated with society (Boerwinkel & Waarlo, 2009; Bowling et al., 2008; Hurle et al., 2013; McInerney, 2002). The ever so rapid changes and advancements in genome science in the 21st century has occasioned, and continues to bring about, a new type of scientific-genomic literacy (Hurle et al., 2013; Sabatello et al., 2019). This type of literacy involves multiple aspects, including: the basics of genomic composition, interaction between genome and environment, and modern medical science (such as which medicine, if any, interacts with the genome).

In the genomic generation, understanding the involvement of genes, human health, and inherited diseases is essential for disease prevention and treatment, human longevity (Collins et al., 2003) and education (Dougherty, 2011; LaRue et al., 2018).

Overall, the evidence accumulated in this literature review has contributed to the motivation of this research to more effectively reach secondary students (especially

underrepresented students) in helping them become better informed citizens and participant scientists in the emerging fields of genomics. The basic rationale for the curriculum presented here and the research methodology is presented in the next chapter.

Genomics and society in secondary school curriculum

In addition to its importance in school curricula, there is an overwhelming concern among economists, scientists, and politicians for improving science education in the United States as a way to keep abreast of advancing fields as many foreign nations, and their economies continue to grow (van Eijck & Roth, 2007). Researchers in the fields of genomics and STEM acknowledge that these scientific fields require higher salaries (Kovarik et al., 2013); and make significant contributions to the U. S. economy (United States Department of Education Office of Educational Technology, 2010). As the U.S. wants to continue to be a world leader in STEM, then each respective state should come to a consensus to support schools and teachers to educate students to becoming future STEM scientists and/or educator. Therefore, part of the emphasis in this genomics curriculum was directed towards important aspects of genomics and society.

Chapter 3: Methods

This is a study of an innovative learning experience on genomic principles and practices designed for secondary school students using mixed methods (qualitative and quantitative evidence) as explained more fully below. The participants voluntarily enrolled in the introductory genomic course as secondary school students who were participating in a special program for secondary school students at a four-year college in New York City. A Likert survey was created and used to assess student attitudes, critical judgments, social and ethical concerns relative to topics addressed in the course, and a multiple-response content achievement test was designed and developed to use to assess knowledge gains. An interview with nine students was used to gain insight into the students' individual perceptions of their individual experiences in the course. The following topics, including more details, are addressed in this chapter: a) Participants and research setting, b) Description of the course: Introduction to Genomics, c) Data-gathering instruments, d) Data analysis and statistical methods, and finally, e) a Summary Chart of Research Questions and Related Evidence is presented to provide an overview of the general plan of the study and the evidence gathered.

Participants and Research Settings

This research was conducted at a public four-year college in New York City, New York. A sample of 25 secondary school students participated in the research, all of which are currently attending various secondary schools throughout New York City, New York. All of the 25 participants were in the age range from 13-15 years (mean = 14, s.d. = 0.93) of age and were enrolled in a free learning opportunity that included this genomic course. It was not evaluated with a grade, nor is it included as part of their formal secondary school required education. Multiple STEM courses are offered including chemistry, anatomy and physiology, and advanced

mathematics. The demographics collected from ninth- and tenth-grade participants included gender and age. All of the 25 participants agreed to participate in the course, and the relevant data-gathering methods as part of the course development and documentation in accordance with the rules of the college where the course was held. Teachers College Columbia University approved this previously gathered data as archival evidence to be used in this thesis research (Subject: IRB Approval: 20-169 Protocol Date: 01/10/2020). The students who participated were assigned a number to maintain anonymity, and all information was secured in a locked location to prevent possible dissemination that might lead to identification of the school where the study was done and any of the participants.

Description of the Genomics Course: Introduction to Genomics

The objective of the course was to develop and design a curriculum that utilizes student-centered, computer-based learning, and other resources from informal learning at AMNH while developing the students' content knowledge of genomics, biology, human health, STEM, and interdisciplinary skills and strategies. This is an appropriate approach for integrating genomics into the majority of general biology curricula (Machluf & Yarden 2013), because, this is one of the gaps in current biology curricula (Wefer & Sheppard, 2008) offered in the majority of secondary school classrooms across the United States. Throughout the course participants had multiple opportunities to independently and collaboratively learn the principles, practices, and scientific evidence-based aspects, of genomic diseases, including working with "big data" using bioinformatics databases. In addition to becoming more fully informed about genomics, the participants will better understand the nature of science, science investigation, and authentic interdisciplinary learning, and become familiar with the (ELSI) associated with genomics. Following the advice of Banta et al. (2012), each of the lessons was developed on vetted design

principles of: a) They have clear pedagogical objectives; b) They are integrated with lessons taught in the lecture; c) They are designed to integrate the learning of science content with learning about the process of science; and d) They require student reflection and discussion.

Course and curriculum development. When developing the *Introduction to Genomics* course, several questions were considered in order to decide which components should and should not be included in developing such a course and more broadly an entire curriculum for secondary school students who were deemed largely unfamiliar with the topics as recommended by R. DeSalle (personal communication, June 4, 2015); Ditty et al. (2010); Maloney et al. (2010); and C. Wray (personal communication, June 28, 2018). These questions were used to critically and reflectively think about the likely needs and interests of the participants, the content, rigor, and the pedagogical approaches applied to the course. Moreover, based on other sources of advice in curriculum design, Boerwinkel and Waarlo (2009) recommended a "Who, What, Why, and How" approach for design of secondary school genomic education experiences. The "who" addresses secondary school students; the "what" includes changes in genomics that have been brought about in the life sciences, society, the changes relevant to and understandable by the student; the "why" are we learning about genomics; and the "How" particularly focused on "can genomics education be structured most effectively in science education and how can genomics concepts and issues be learned and taught most effectively." (p. 21)

The *Introduction to Genomics* course was developed through insights gained from prior experiences teaching genomic and STEM courses, collaboration with the Sackler Institute for Comparative Genomics at AMNH, and professional development at the Jackson Laboratory. Student professional development and informal learning at AMNH has shown to be effective in stimulating secondary school science learning, interests, and career development in genomics

and STEM (Cvijovic et al., 2016; Munn et al., 1999). One of the main goals was to have the participants engage in lifelong learning of genomics education, conceptualize biological processes, collaborate with developing solutions, and acquire new vocabulary terms from the course that they generally would not have learned in their current secondary school science class. Putting these factors into place would highly support the process of lifelong learning of genomics, biological, and human health concepts. To further test the validity as to why this content is practical, meaningful, interdisciplinary, and applicable to areas of their lives the participants were introduced to relevant websites (Appendix B). These websites further enhanced their conceptions of genomics as well as addressing the key points mentioned throughout the genomics course. Based on my previous observations of Internet use and searches among primary and secondary school students and science teachers, it is essential for the participants to become familiar with reputable websites that are recognized throughout the scientific community. Southworth et al. (2010) promote the use of a virtual laboratory environment to supplement and/or in-place-of a traditional hands-on classroom laboratory. For more than twenty years "educational technology research have demonstrated the power of cyberlearning in helping students construct rich mental models of genetics." (p. 3)

Utilizing a number of CBL pedagogical skills from Clarke (2001) I focused on the essential terms/vocabulary, genomic concepts and processes to represent clear principles instead of rote facts and details by removing certain terms related to cellular organelles with the exception of the nucleus. Some of the cellular organelles were removed because, although it is essential to learn the cellular organelles to better understand molecular biology, it was more important for students to become familiar with scientific concepts that they have not accustomed to learning.

***Pedagogy*.** The Biological Sciences Curriculum Study (BSCS) 5E model engage, explore, explain, elaborate, and evaluate provided an effective alternative to traditional and/or autocratic pedagogy (Bybee & Van Scotter, 2006; Rodriguez, Allen, Harron, & Qadri, 2019), which tends to focus mainly on one type of activity, processing symbolic information (Collins, 2009). Using the BSCS approach, the participants were encouraged to use their prior knowledge to **engage** interest in genomics and related subjects and begin to **explore**, how these topics occur in the natural world. After acquiring an understanding of genomics, they **explain** the particular phenomenon they learned and **elaborate** their understanding through new experiences. Lastly, students **evaluate** their comprehension and apply it to real-life situations.

> Many secondary school science teachers in urban schools are restricted by the science curriculum dogma and have limited autonomy with which topics they are and willing to, teach. Although their pedagogy may be superlative, many have difficulty developing a learning environment conducive to student-centered learning, individual interests, CBL, collaborative learning, and especially learning through human/student error. The (BSCS) 5E model inspires students to gradually learn and master a subject while gaining control of their own learning and developing autonomy. Science teachers act as a facilitator and monitor student progress Bybee & Van Scotter, 2006).

Course structure and design. Each class began with an essential question of the day that was intended to elicit a response from the participants and orient them to the topics for the class session. Answers were listed on the board and briefly elaborated on. Examples include, How has DNA technology impacted law enforcement?; Is it ethical for major sport organizations to sequence an athlete's genome?; What are three examples of a genetic disease? This was followed by a brief lecture pertaining to the topic of discussion. This included listing genomic terminology, elaborating on biological or scientific processes, or links to society and real-world applications.

Utilizing CBL as an additional pedagogical framework, participants were introduced to genomic and STEM-based websites (Appendix B) that correlated with the topic of discussion.

For example, after briefly lecturing on polygenetic diseases, a brief exploration of how to utilize, navigate, and obtain information from the cdc.gov was emphasized. Participants and instructor then continued utilizing the 5E model as well as other pedagogical skills and strategies intended to enhance the student-centered approach of the course. Lastly, videos (previously referred to as bio bulletins and science bulletins from the AMNH website) further elaborated and extended the topic of discussion by providing brief 2-3-minute videos followed by questions that were discussed collaboratively in the class.

Implementation of the course and design of the study

To ensure that the course, which was the focus of the research, was best designed for the participants, I used prior genomic resources, curriculum, lesson, pedagogical skills and strategies, and student feedback from a similar genomic course that was taught on three separate occasions. The major difference between the current research and the previous courses taught was, the use of a Likert-scale and in-depth student interviews.

The genomics course was taught three times previously before this study was undertaken. However, at that time, none of the relevant evidence from the participants responses to the research instruments was gathered. This prior experience was valuable in designing the course and methodology used in this research study.

During the first session of the course (Day 1) a general questionnaire was administered consisting of background information and prior experience in learning about topics pertaining to genomics and genetics. In addition, a Likert pre-survey was administered to document the participants percepts of ethical, legal, and social topics related to genomics, biology, and human health; and beliefs and attitudes associated with genomics in general and more specifically about its use in scientific research (Appendix C). Day 1 also focused on measuring the initial status of

the students' knowledge by administering a 25-multiple-choice content achievement test. (Appendix D), it was constructed to measure the level of prior content knowledge in genomics, biology, and human health concepts. It also provided some background information on the students' prior knowledge (Latimier, Riegert, Peyre, Ly, Casati, & Ramus, 2019) to help guide the more student-centered approach used in the learning experiences. These data gathered from the three replications of the course were compiled into one composite set of results and used to address the research questions posed in this study.

Data Gathering Instruments

Data was gathered by the following means as explained more fully in the following subsections: a) Likert survey of attitudes and critical judgment regarding topics related to genomics, b) Learning outcomes assessment, and c) and interview evidence.

Likert survey evidence. A Likert survey with 15 items, and five options per item (Appendix C), was designed to tap some of the critical judgmental, affective, and emotive orientations of the students who participated in the course. The survey consisted of three sections designed to assess the following dimensions: a) opinions about learning modern genomic and genetic principles, b) ethical choices associated with genomics, and c) beliefs and attitudes associated with genomics. The differences in the post-survey responses compared to those in the pre-survey responses provided evidence of changes in these 'affective dimensions.'

Learning outcomes assessment. The pre-and-post content achievement test (Appendix D) consisted of 25 multiple-choice questions of the following topics: Five of the questions (Questions 1-5) addressed basic concepts of genetics (cellular components and processes, chromosome structure and function, inheritance), twenty of the questions (Questions 6-25) addressed genomic principles and practices (analyzing DNA, bioinformatics, HGP, HMB, and

ELSI). The purpose of administering the pre-test was to gather evidence of the participants' prior content knowledge pertaining to modern biological, genomics, human health, and ELSI principles as a baseline for comparison with any achievement gains as assessed by the post-test; and to help set the breadth and depth of content that was introduced during the duration of the course. The difference in the means of the pre-test and post-test scores was used to assess student achievement in the course.

Interview procedures and evidence. Interviews were collected to obtain qualitative evidence beyond that of the Likert surveys. Nine students volunteered to be selected to be respondents; five females and four males. The individual interview with each respondent was held at the very end of the study. The items in the Likert survey served, partially, as a guide to more fully probe students' perceptions of the course experiences. The questions used in the interview are presented in Appendix G. According to Paradis et al. (2016) specific advice on proper interview procedures included the importance of using open-ended questions that are specific enough to yield coherent responses across respondents, yet broad enough to invite a spectrum of answers. Conducting an interview with participants provided additional evidence of the participants' percepts in the form of expanded (typically qualitative) narrative beyond the qualitative and semi-quantitative data. This was largely intended to provide more open-ended evidence of participants' reporting of the learning experience and it provided an opportunity for the participants to elaborate on responses made previously to the Likert-scale survey items. Thus, the Likert-scale survey items served as a scaffolding method for the interview questions presented initially to the respondent, as a way of focusing the interview and providing a context to encourage more elaborate narrative by the respondent. The interviews were individually administered, and not audio-taped. Detailed notes were taken including verbatim quotations of

the student's narrative, where appropriate. The respondents' narrative evidence was used to document and analyze themes that emerged based on my analytical and critical reading of each respondent's narrative.

Data Analysis and Statistical Methods

The results of the Likert survey responses, within each if the three sections of the survey, were tabulated as frequencies for each item, and presented as a table for the pre- and post-survey results. Additionally, bar graphs were constructed using Excel as visual evidence of the change in the respondents' responses toward a more favorable ('Agree or Completely Agree') position for each item. This directionality was used as a concise way of exhibiting trends in the respondent's change in position relative to each Likert item, in addition to the more detailed evidence in the frequency tables. The scores of each student on the multiple response pre- and post-test were tabulated and the means ± standard errors (s. e.) for the pre- and post-test were reported. A paired t-test was used to assess the significance of the mean difference, because the two sets of data are not independent. A p of ≤ 0.05 was used to judge the significance of the t-test results. Evidence from the interviews was qualitative and no statistical analysis was done.

Summary Chart of Research Questions and Related Evidence

The research questions, including the sources of evidence and means of documentation and analysis for each of the research questions, are presented as a summary table in Appendix F. This provides a concise summary of the overall research design and the kinds of evidence gathered to address each of the research questions as explained in more detail in the foregoing sections of this chapter.

Chapter 4: Results

The results for each of the research questions will be addressed sequentially beginning with Research Question 1.

Research Question 1

Research Question 1 addressed the following: Based on affective evidence, how did secondary school students perceive and critically judge, content topics learned in a course on modern genomic principles and practices?

The results for the first research question regarding the participants' opinions about learning modern genomic and genetic principles, ethics, and beliefs and attitudes are presented in Tables 4.1 to 4.3 and Figures 4.1 to 4.3. Table 4.1 and Figure 4.1 presents the pre-and post-survey results of the respondents' opinions for the five items in Section 1 of the survey on the topic of 'Learning modern genomic and genetic principles.'

Results for Section 1 of Likert survey. Table 4.1 and Figure 4.1 present the results.

Table 4.1. Pre-and-post-Likert survey (Section 1) results of the respondents' opinions about learning modern genomic and genetic principles.

	Pre					**Post**				
Likert Items	CD	D	N	A	CA	CD	D	N	A	CA
1-Important to learn genomics	1 (5)	9 (43)	10 (48)	1 (5)	0 (0)	0 (0)	0 (0)	0 (0)	10 (48)	11 (52)
2-Improves Understanding	0 (0)	0 (0)	0 (0)	11 (52)	10 (48)	0 (0)	0 (0)	3 (14)	8 (38)	10 (48)
3-Environment and genome	2 (10)	4 (19)	9 (43)	2 (10)	4 (19)	0 (0)	2 (10)	5 (24)	10 (48)	4 (19)
4-Important to human society	0 (0)	8 (38)	4 (19)	4 (19)	5 (24)	0 (0)	0 (0)	2 (10)	6 (29)	13 (62)
5-Better Prepared	0 (0)	7 (33)	4 (19)	4 (19)	6 (29)	0 (0)	0 (0)	3 (14)	7 (33)	11 (57)

Note: Frequencies are presented in the first line and percentages are beneath each entry in parentheses.

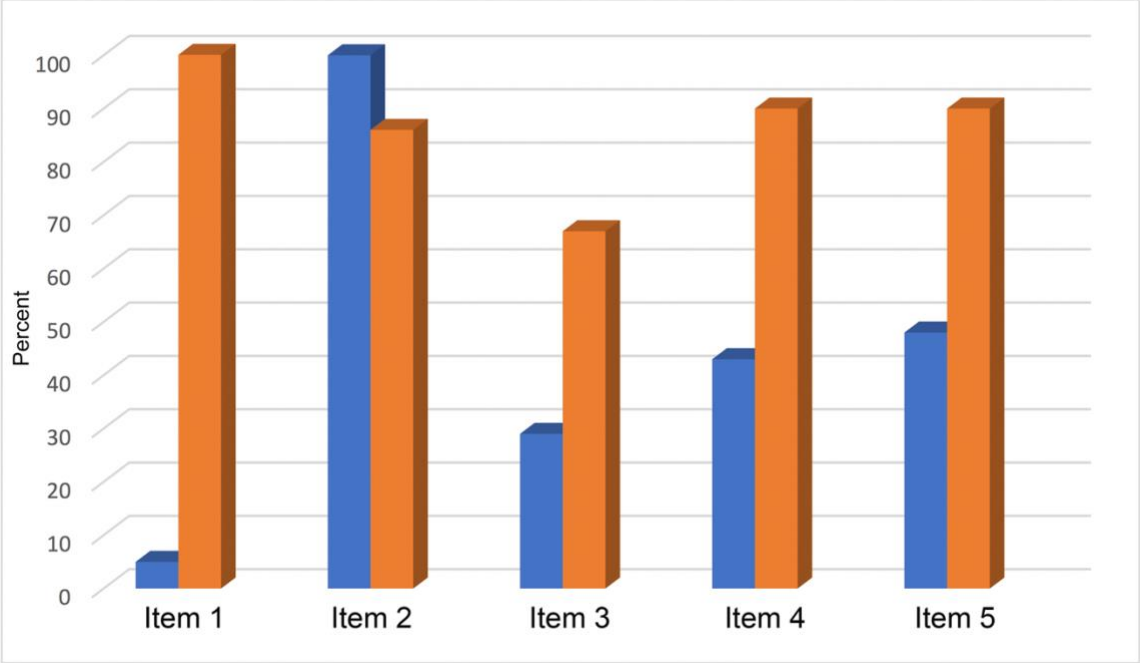

Figure 4.1: Bar graph of the percentage of the total 'Agree and Completely agree' (A and CA) responses for the Likert scale survey (Section 1) items 1-5 (Section 1) related to opinions about learning modern genomic and genetic principles. Pre-survey (blue) and post-survey (red) results.

The results of the Likert survey items in Section 1 show that for all of the items except Item 2, the post-survey responses were more favorable than the pre-survey responses. There was a substantial increase for Item 1 in the percentage of the participants believing that it is important to learn genomics, zero to 100%. Item 1 is of particular interest, primarily because it was one of the items in this set that had the largest gain in positive responses with respect to learning genomics and improving an understanding of STEM and/or science courses. For Item 3, 67% 'agreed or completely agreed' that the environment affects a person's genome, this was a 38% gain beyond the value in the pre-survey results. Approximately 90 % of the participants 'Agreed or Completely Agreed' with Item 4 in the post-Likert survey regarding the importance of studying genomics in so far as these ideas are increasingly important with ELSI towards human

society. This was a large shift from the 43% who initially totally agreed with this statement, as well as the 38% who initially disagreed with it. Lastly, 90 % of the participants 'Agreed or Completely Agreed' with the statement in Item 5, concerning the extent that learning genomics will better prepare them for college and prepare them for a career in a field of science and/or medicine. This was a shift of position from 33% who disagreed in the pre-Likert survey for this item, compared to the post-survey results where zero % disagreed for Item 5.

Results for Section 2 of Likert Survey. The pre- and post-survey results for the responses to items in Section 2 of the Likert survey related to ethical choices associated with genomics are presented in Table 4.2 and Figure 4.2.

Table 4.2. Pre-and-post-Likert survey (Section 2) results of the respondents' ethical choices associated with genomics.

	Pre					**Post**				
Likert Items	CD	D	N	A	CA	CD	D	N	A	CA
1-Correct "Bad genes"	1 (5)	3 (14)	7 (33)	5 (24)	5 (24)	2 (10)	5 (24)	5 (24)	6 (29)	3 (14)
2-Alter the genome	3 (14)	1 (5)	9 (43)	4 (19)	4 (19)	6 (29)	12 (57)	3 (14)	0 (0)	0 (0)
3-Increase life span	8 (38)	0 (0)	4 (19)	6 (29)	3 (14)	3 (14)	5 (24)	6 (29)	6 (29)	1 (5)
4-Baby's gene	2 (10)	0 (0)	3 (14)	9 (43)	7 (33)	0 (0)	4 (19)	6 (29)	8 (38)	3 (14)
5-Neanderthal	8 (38)	6 (29)	3 (14)	2 (10)	2 (10)	5 (24)	6 (29)	5 (24)	3 (14)	2 (10)

Note: Frequencies are presented in the first line and percentages are beneath each entry in parentheses.

Figure 4.2 provides visual evidence of the changes in the respondents' percepts from the Likert pre- to post-survey for items 1 to 5 of Section 2, particularly illustrating the wide

variability in the magnitude of the response change, while illustrating that most of the changes were more negative (Items 1 to 4).

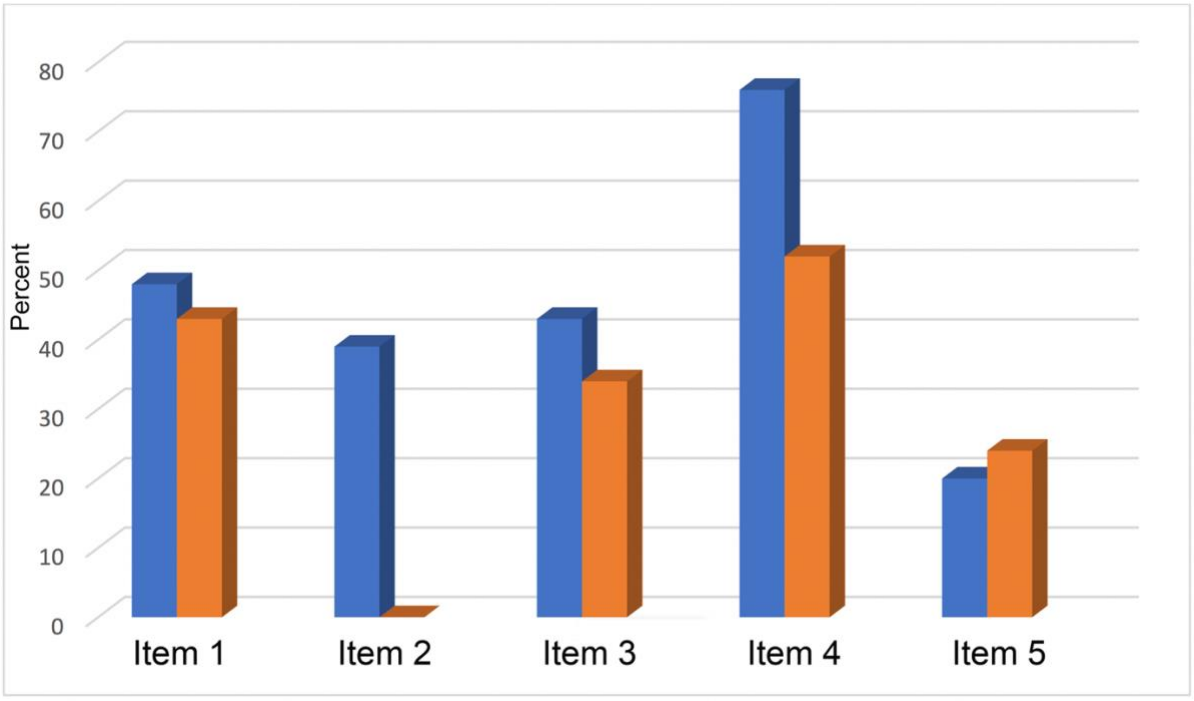

Figure 4.2: Bar graph of the percentage of the total 'Agree' and Completely agree' (A and CA) responses for the Likert scale survey (Section 2) Items 1-5 relate to ethical choices associated with genomics. Pre-survey (blue) and post-survey (red) results.

Generally, the change in pre-survey to post-survey Likert scale responses for Items 1 to 4 in Section 2 of the survey was toward a less positive opinion (lower percentage of total 'Agree and Completely agree' responses). However, Item 5 related to doing molecular genetic research on Neanderthal fossil remains showed a very small increase in the percentage of positive responses (increasing minimally from ca. 20 to 24 %). Furthermore, as shown in Table 4.2, a substantial proportion of respondents were negatively predisposed to doing this kind of genomics research, in both the pre- and post-survey results. Overall, the tendency toward less positive responses for Items 1 to 4 indicates that the respondents were less favorable to human genomic alterations, especially "Altering the human genome" (Item 2), and to some extent altering

“Baby’s genes” (Item 4). Item 5, that addressed the extinct human populations of Neanderthals, seems to have elicited relatively little positive orientations either before or after the genome lessons. Moreover, with respect to evidence in Table 4.2, it is interesting to note that the post-survey responses showed considerable ambivalence for four of the five items, with 24 to 29% of the respondents choosing ‘Neutral' (Items 1, 3, 4, and 5).

More specifically, the results for Item 1 related to ‘correcting bad genes’ initially had 48% who ‘Agreed or Completely agreed’ in the pre-survey; and in the post-survey, there was not much difference in the responses (43% ‘Agreed or Completely agreed’). Thus, the change was minimal. With respect to Item 2, ‘on altering the genome of an individual’, 43 % of the respondents ‘Agreed or Completely Agreed’ with this item on the pre-survey, but there was zero percent on the post-survey (Figure 4.2), which was a major change in opinion for this sample of respondents. For Item 3, 43% were initially favorable to ‘altering a person’s genes to increase their lifespan,’ but the results for the post-survey (34%) showed a slightly less overall favorable response. Thirty-eight percent completely disagreed with Item 3 on the pre-survey; whereas, on the post-Likert survey, 14% disagreed. In Item 4, 76% were in total agreement on the pre-survey with respect to ‘correcting a baby’s genes before the baby is born to improve its health’ (Figure 4.2). However, less (52%) were in total agreement to this item on the post-survey. Of particular interest, the percentage of students who remained ‘Neutral’ on all of these items in Section 2 of the post-survey was in the range of 24-29%, except for Item 2 (14 %). This was the item where most of the respondents were strongly unfavorable in the post-survey. Overall, the percentage of ‘Neutral’ responses suggests that a good number of the students refrained from making a final judgment (favorable or unfavorable) about some of these cases.

Results for Section 3 of Likert Survey. Section 3 of the Likert survey focused more specifically on the use of genomics in research, including aspects of research data, possible medical remedial procedures, genomic diseases, and use of comprehensive data bases containing individual DNA evidence. The results of the Likert pre- and post-surveys are presented in Table 4.3 and Figure 4.3. Items 1 to 3 showed varying degrees of decrease in positive percepts; while Items 4 and 5 showed varied increases in positive orientation toward strongly 'Agree.'

Table 4.3: Pre-and-post-Likert survey (Section 3) results of the respondents' beliefs and attitudes associated with genomics.

	Pre					**Post**				
Likert Items	CD	D	N	A	CA	CD	D	N	A	CA
1-Medical Research	0 (0)	2 (10)	8 (38)	4 (19)	7 (33)	2 (10)	4 (19)	5 (24)	7 (33)	3 (14)
2-Genetic research	3 (14)	5 (24)	8 (38)	5 (24)	0 (0)	9 (43)	7 (33)	2 (10)	3 (14)	0 (0)
3-Microscopic	0 (0)	2 (10)	2 (10)	9 (43)	8 (38)	7 (33)	5 (24)	5 (24)	4 (19)	0 (0)
4-DNA database	9 (43)	9 (43)	3 (14)	0 (0)	0 (0)	5 (24)	7 (33)	5 (24)	4 (19)	0 (0)
5-Polygenetic diseases	3 (14)	2 (10)	3 (14)	4 (19)	9 (43)	0 (0)	0 (0)	1 (5)	6 (29)	14 (67)

Note: Frequencies are presented in the first line and percentages are beneath each entry in parentheses.

The data in Table 4.3 is presented visually in Figure 4.3, particularly focusing on the change from, pre- to post-survey for Items 1 to 5 of Section 3 in the Likert survey. The general trend toward a more favorable response to Item 5, and a decline in positive perspective for Item 3, is particularly evident.

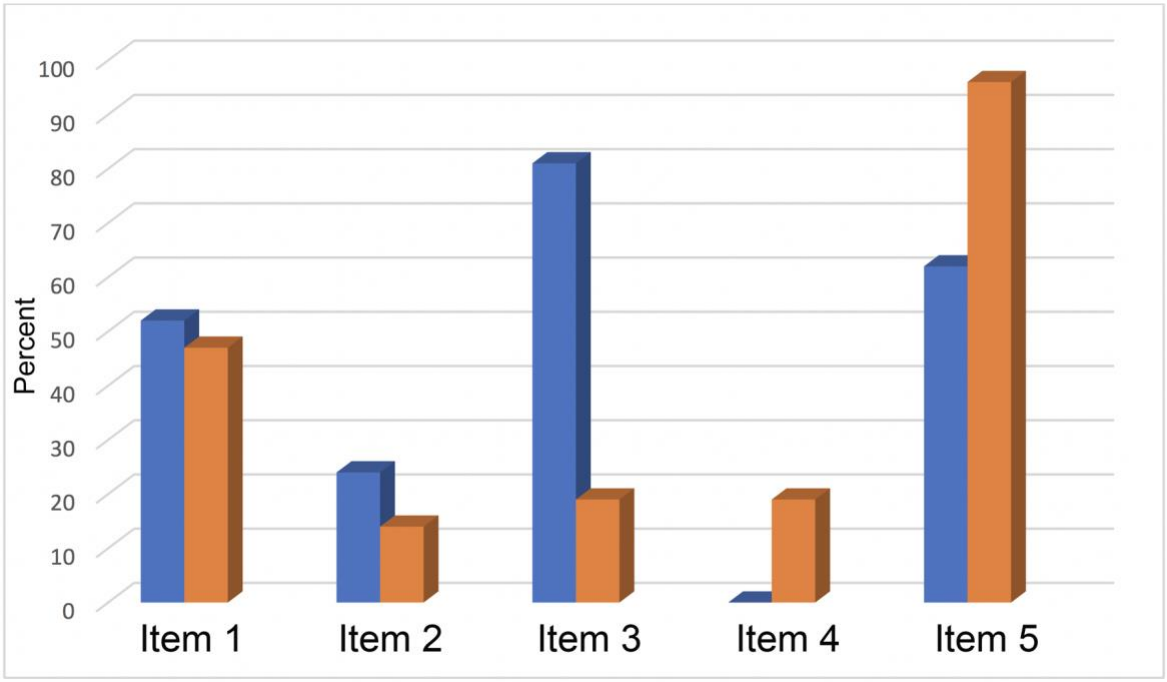

Figure 4.3: Bar graph of the percentage of the total 'Agree and Completely Agree' (A and CA) responses for the Likert scale survey (Section 3) Items 1-5 related to 'beliefs and attitudes associated with genomics research and applications.' Pre-survey (blue) and post-survey (red) results.

There was a noticeable change from pre-survey to post-survey Likert scale responses for Items 4 and 5 in relation to the increase of 'Agree and Completely agree responses' (Figure 4.3). However, Item 3 was also particularly noticeable because of the strong change from a more positive stance in the pre-survey towards a less positive stance in the post-survey (lower total agreement, Figure 4.3). This is a rather complex item involving microscopic robots (DNA microarray or biochips) to improve mutated genes. Overall, the percentage of students who remained 'Neutral' on items in the post-survey varied markedly from 5 to 24%, although a neutral response of 24% was recorded for Items 1, 3, and 4.

Analysis of composite results for Sections 1 to 3 of Likert Survey. Figure 4.4 presents evidence for the net change in percentage of responses from pre-to post-survey for degree of agreement (A and CA) for each of the items in the three sections of the Likert survey. That is, the

vertical columns in the graph indicate to what extent the responses tended to increase in agreement on the post-survey (positive values in blue) or tended to become less favorable (lower percentage of agreement) to the item on the post-survey (negative values in red).

Overall, there was a net increase in the percentages tending toward a positive response to Items 1 to 5 in Section 1 (1.1 to 1.5, Figure 4.4) on 'opinions about learning modern genomic and genetic principles' (mean ± s.e. = 38.6 ± 17.2). For Items 1 to 5 in Section 2 (2.1 to 2.5, Figure 4.4) on 'ethical choices associated with genomics,' the net change was toward more negative (-14.4 ± 7.3). The response to items 1 to 5 in Section 3 (3.1 to 3.5, Figure 4.4) was mixed, with a small net negative change in percent toward less approval to the items (-4.8 ± 16.4). The relatively large s.e. indicates the diversity in the responses, particularly with items in Sections 2 and 3 being more negative than those in Section 1.

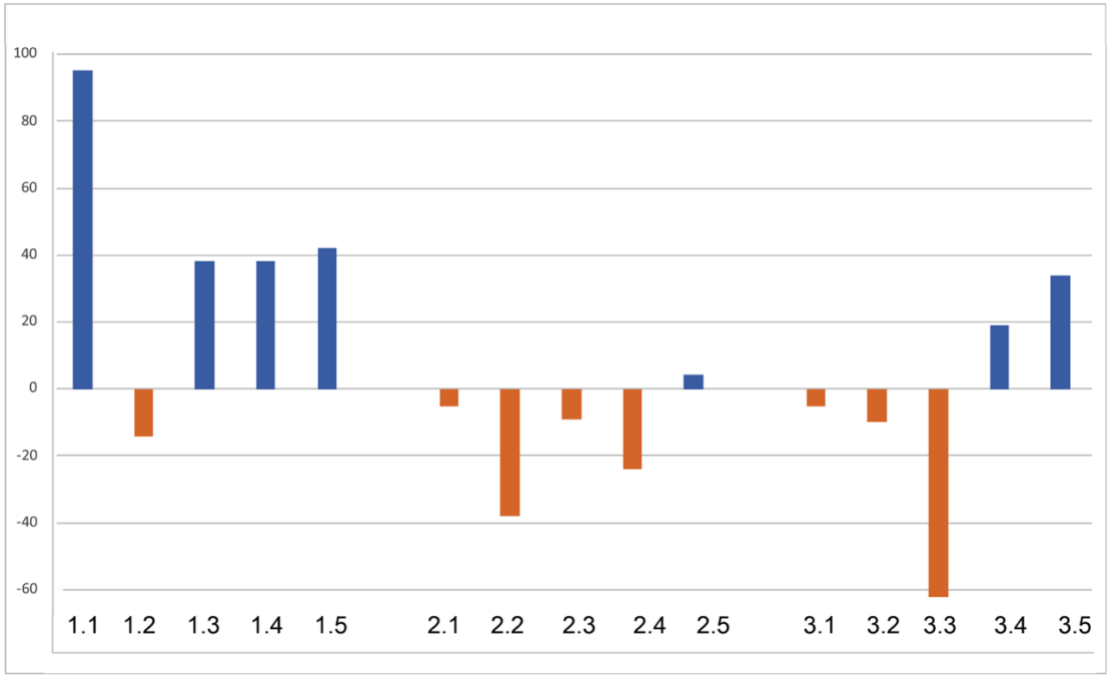

Figure 4.4: Net percent change toward more positive responses (blue bars) or toward less positive responses (red bars) to the Likert survey items in Sections 1 to 3: Section 1 (1.1 to 1.5) on 'opinions about learning modern genomic and genetics principles,'; Section 2 (2.1 to 2.5) on 'ethical choices associated with genomics; and Section 3 (3.1 to 3.5) on 'beliefs and attitudes associated with genomics research and applications.'

In general, the evidence in Figure 4.4 indicates that there was an overall increase in positive orientation to learning genomics and its principles (Section 1) after completing the genomics lessons, but accompanied by a tendency to be more skeptical about some of the social and scientific benefits of genomic engineering and medical applications to humans (Section 2), as well as increased concern about the merits of some aspects related to possible future use of genomics in research and its applications (Section 3).

Research Question 2

Research Question 2 addressed the following: Based on cognitive evidence, how much did secondary school students learn when they participated in a course on modern genomic principles and practices?

Table 4.1: Summary of Raw Data from the Pre- and Post-test.

Participant code numbers	Pre-test scores	Post-test scores
1	60	80
2	55	85
3	50	75
4	60	90
5	60	90
6	55	75
7	70	80
8	55	85
9	65	80
10	65	85
11	70	90
12	65	85
13	55	80
14	70	90
15	55	75
16	60	90
17	65	90
18	70	85
19	70	90
20	55	80
21	60	80
22	55	85
23	65	85
24	65	80
25	65	90

The mean scores ± standard errors are 61.25 ± 1.19 for the pre-test and 83.75 ± 1.03 for the post-test. The paired *t*-test for the difference in the means between the pre-and post-test was highly significant, t =19.3 ($p < 0.0001$, df =23). Overall, the mean gain was 22 scale points within a 100-point total score.

Research Question 3

Research Question 3 was: Using individual interview evidence, what are the major perceptions that the secondary school students expressed throughout the duration of the course? This research question addressed evidence related to the participants' perceptions of their learning experience. There were five interview questions, and nine participants who were interviewed.

Interview question 1. What were some interesting topics that you learned throughout the duration of the course? Of the nine participants that were interviewed about their interests in the course, all of them did find the course to be interesting and the course did clarify some genetic concepts that they previously misunderstood. They were also asked if there were any genomic terms that were unfamiliar to them prior to the course, and they all answered yes. The responses that came up most frequently were: Genome-Wide Association Studies (GWAS), ELSI, Genetic Information Nondiscrimination Act (GINA), micropipetting, HMB, pharmacogenomics, and epigenetics.

Interview question 2. Throughout this course we learned and focused on polygenetic and monogenetic diseases. Was this a topic that you found interesting? All of the nine participants agreed that learning this topic helped clarify and dispel some misconceptions pertaining to inherited and acquired diseases. Including categories such as: sex-linked, autosomal

dominant, autosomal recessive, and chromosomal abnormalities. Moreover, there were specific diseases that were of particular interest, which optimized their proclivity to enhance knowledge.

Interview question 3. Did you enjoy utilizing CBL throughout the course? Given the innovative and interactive nature of CBL, all of the nine participants were very comfortable and stated that their learning was influenced due to the student-centered learning framework (learning at their own pace as an autonomous learner).

Interview question 4. Were there any particular topics that you enjoyed learning regarding ELSI? Each of the interviewee responses demonstrated that they were aware of and believed that they were very successful in making intuitive decisions towards ELSI of genomics. Many of the participants had varying interests towards a particular topic of ELSI, including: genetic discrimination, designer babies, personal genomics and healthcare, and genetic engineering. One specific example was with Item 4 on Section 3 of the Likert survey that addressed the issue of maintaining public data bases on human DNA information (Table 4.3). Seven of the nine participants interviewed 'Completely disagreed' with Item 4. An excerpt during the interview with participant #12 highlights the lack of ELSI at their current school. The following are excerpts from the interview responses that pertain to Interview question 4; the prefix "R" represents the interviewer's comments or questions, and each respondent's answer is coded with the respondent's participant number (#).

R: You mentioned that you were interested in ELSI, any particular topic that you were interested in learning?

#12: Yea I really liked when we did our presentations, I did mine on the DNA database. I think most of us enjoyed picking our own topic, but when you showed us about the Golden State Killer, it really was interesting to learn how the world is changing.

R: What do you mean by that?

#12:Like how the government and society is being watched and there really isn't as much privacy as people think. I just think it was cool learning about this more often. At first, I was total against it, but now I think there is some proof to why it's being done in the UK. I pretty sure that from what we looked at on the websites that we are all going to have our info in some

database. Like now that you told us about the inheritance websites, I told a few of my friends that it is not worth doing.

R: OK, why?

Because we are all going to be watched or someone will be able to hack us or something like that.

R: Do you learn about ELSI in your school?

#12: No, I wish we did. I like talking and learning about ethics and how it affects society. We do a lot of labs and cool activities, but we don't use the websites that you showed us or get to talk about many things that we don't realize. Like when we were talking about gene editing and the designer babies, it was just cool to know that this type of science exists.

Interview question 5. There were two days that we focused on genomic careers. Do you think that you would pursue a career in genomics? Seven of the nine participants explained that they may continue to enroll in similar STEM courses that focus on student-centered learning and genomic/STEM careers. They realized that they were ultimately responsible for their career trajectory, however the proper resources were not available at their school or their science teachers or guidance counselors were novices in STEM/education and college placement for STEM careers. Several expressed they were inspired and would study genomics in college.

The following are excerpts from the interview responses that pertain to Interview question 5. (R=researcher):

R: Do you believe that this course prepared you to enroll in a career in genomics?

#20: Oh yes definitely. It's a very interesting subject.

R: Can you elaborate?

#20: Well all of the topics that we learned are interesting and I think that I have what it takes to become a scientist. I really liked when you learned about the different careers from the website. Most of those careers I didn't know existed and we definitely don't learn them in our other science class.

R: Which genomic career are you interested in pursuing?

#20: Probably forensics or something involved in law and government. I mean what we learned about ELSI was also very interesting so I think that would be another career choice. You see that is the dilemma that I have sometimes and I have no one at my school to help. They are good teachers and guidance counselors but there are so many students.

Chapter 5: Discussion

The participants in this study were 25 volunteer secondary school students from public schools in New York City. All 25 students completed the genomics pre- and post-achievement test, 21 completed the pre- and post-Likert surveys, and nine were interviewed to gain insight into their perceptions of the content in the course. In this chapter, the results for each of the three research questions will be discussed in sequential order, including a cross comparative analysis and discussion of the results for the three Likert-survey items that were used in addressing Research Question 1. Finally, the last sections include: Implications and Relationships to the Literature, Summary of Strengths and Limitations, Including Transferability and Scalability, Implications for Future Research and Applications, and conclusions.

Research Question 1

This question addressed the following dimension: Based on affective evidence, how did secondary school students perceive and critically judge, content topics learned in a course on modern genomic principles and practices?

Overall, there was generally a positive response to all of the items, excluding Item 2, for Section 1 of the Likert survey pertaining to the participants opinions about learning modern genomic and genetics principles, with 100% cumulatively agreeing in the post-survey that it is important to learn about genetic/genomic diseases (Item 1). However, in the post-survey, the respondents were less favorable that learning genomics will improve their understanding of other courses such as biology and related sciences (Item 2). In response to this item in the pre-Likert survey, 0% responded ‘Neutral;’ and in the post-Likert survey,14% responded ‘Neutral.’ The overall positive responses to the other items addressing learning modern genomic and genetic principles is consistent with the literature findings that in general, genomic education is a

positive factor associated with learning and improving modern STEM education (Dressler et al., 2014; Hurle et al., 2013; McInerney, 2002).

The participants' responses to Section 2 of the Likert survey, pertaining to ethical choices associated with genomics, were particularly less favorable; especially in response to the items in the post-Likert survey. For example, 38% of the respondents in the pre-Likert survey chose 'Agree' with altering the human genome (Item 2). Subsequently, however, on the post-Likert survey, 0% of the respondents selected 'Agree' with Item 2. This change in response (38% pre-Likert survey and 5% post-Likert survey) is likely due to acquiring new content knowledge and conceptualizing the pros and cons of the ethical choices involved. This change may have resulted from the information gained during their experiences in the course including their critical discussions with their peers. Their change in opinion is consistent with conclusions of scientists and science educators regarding ELSI, eugenics, genome editing, GMOs, and cloning. This suggests that the students, being novice learners relative to these principles initially had a less negative view, and then eventually becoming familiar with genomic and ethical principles, they chose a more critical stance.

Section 3 of the Likert survey measured the beliefs and attitudes associated with genomics. Similar to the students' responses to the first and second items of Sections 1 and 2 (regarding opinions about learning modern genomic and genetic principles and ethical choices associated with genomics), student responses to Section 3 of the Likert survey also varied from pre- to post-survey. For Items 1 to 3, the responses shifted toward less favorable. However, for Items 4 and 5, there was a modest shift toward more favorable In the pre-survey for Item 4, 86% of the participants chose 'Disagree' for the proposal of developing a National DNA Database. On the post-Likert survey, the percentage who disagreed decreased from 86% to 57%, which is a

29% decrease. This was accompanied by a small increase in those who 'Agreed' on the post-Likert survey (19 %). Moreover, for Item 3, there was a 0% response in the pre-Likert survey who chose 'Completely disagree' with the idea of developing microscopic robots to enter into human cells to examine and correct errors in human genes. However, on the post-Likert survey the responses were 33% who chose 'Completely disagree.' This indicated that they likely had acquired a more critical perspective on the ethical concepts pertaining to DNA Microarrays that were part of the likely technology related to microscopic robots in human medicine. Carver et al. (2017) reported similar shifts in beliefs and attitudes in their Likert survey study. These relatively strong comparative results between this study and that of Carver et al. (2017) suggest that the student-centered approaches used in this study can enhance students' critical judgements about scientific decision making, especially as it may affect major societal or ethical dimensions.

In the Carver et al. (2017) study on college student's knowledge, beliefs, and attitudes pertaining to genetics and genomics, there was mixed perceptions involving genetic determinism and the interaction between different types of knowledge and values. It is common for people to have rooted beliefs that may not be altered regardless of any newly acquired knowledge that one has gained. This kind of deeply developed prior conceptions may account for why the results for Section 3 were varied, with mixed perceptions pertaining to genomics and ELSI, before and after taking the course. Comparative analysis of results for Sections 1 to 3 of the Likert survey.

Combined evidence from Figure 4.4 is presented in this section.

The comparative analysis of the responses to the 15 Likert-survey items in the three sections of the survey as presented in Figure. 4.4 provides some insights into the pattern of relationships among the evidence gathered for each of the three sections of the survey. The data in Figure 4.4 provides evidence of the dynamics of the changes in students' responses to the

items in the three sections of the Likert Survey. As the participants became more positively aware of the importance of learning genomics, they also showed increasingly more critical awareness of the issues in Sections 2 and 3, sometimes shifting their stance from one pole of the item dimension to the other (e.g., from the 'Agree' pole toward the 'Disagree' pole). Additionally, some of their responses in Sections 2 and 3 remained neutral, or shifted notably from one opinion toward more neutral. For example, in Section 1, 48% in the pre-Likert survey were neutral (N) towards the importance of learning genomics (Item 1). In the pre-Likert survey 0% responded neutral. This was the most significant change in neutral responses in all of the sections. In section 2, 43% in the pre-Likert survey were neutral (N) for altering the genome of a baby before birth to enhance its eventual length of life (Item 2). In the post-Likert survey 14% chose neutral (N) for Item 2, this is a 29% decrease from pre-to-post Likert response. In section 3, Item 2 also had a significant change in response to the participants choosing neutral in the pre-and-post Likert survey. Thirty-eight percent were neutral towards parents choosing whether a mother will give whether a mother will give birth to a boy or a girl. Only 10% remained neutral in the post-Likert survey. This was a 28% decrease from pre-to-post Likert response. In general, while there were major shifts in the opinions of the participants toward one pole or the other for some of the items, there also remained a pool of participants who chose to remain more undecided for some of the issues in the Likert-scale items.

Overall, the combined evidence in Figure 4.4, showing a major change in the respondents' position toward largely agreeing with the importance of learning genomics concurrent with a major shift toward disagreeing with some aspects of genomic research and its applications to societal issues, suggests that the students were making critical, reflective judgments about issues in genomics as they became better aware of the merits of learning about

genomics. Furthermore, given the evidence that some respondents chose to remain 'Neutral' regarding some of the items in Sections 2 and 3, suggests that they withheld strong judgements. This tendency to remain neutral rather than take a polar position may be additional evidence of the diverse ways the students applied their critical reflective analysis of the Likert survey items, especially in Sections 2 and 3.

Comparative analysis of Likert-scale items in Sections 1 to 3. Based on survey theory, Likert-survey items should be designed to assess a particular dimension or theme in each item. Moreover, Likert items can be categorized based on the format of the item into one of three categories: a) *Position* where the item contains a statement that addresses an opinion about policy or procedure that the respondent considers in making a response to the options in the scale item, b) *Evaluation*, requiring the respondent to evaluate a statement with respect to criteria or a criterion, and c) *Sentiment*, where the item contains information of emotional and largely affective aspects. There were no items categorized as *Sentiment*. However, evidence for the participants' sentiments (what they enjoyed in the genomics course and their interests) was obtained using interview questions as discussed in the section below on Research Question 3.

The items in the Likert survey (Appendix C) were categorized largely as either *Position* or *Evaluation* items. For example, Items 1, 2, and 5 of Table 4.1 were categorized as *Position* Items. In the post Likert-survey, 100% were positive for Item1; 86% were positive for Item 2, with 14% remaining neutral; and 90% were positive for Item 5 with 10% remaining neutral. Item 4 of Table 4.1 was the only Item of all three sections categorized as an *Evaluation* item. In the post Likert-survey 91% were positive, and 9% remained neutral.

In Table 4.2 of the post-Likert survey the *Position* responses we not as positive as the previous section. For example, 43% were positive for Item 1, and 24% were positive for Item 5. Items 2, 3, and 4 were less positive.

In Table 4.3 of the post-Likert survey the *Position* responses for Items 4 and 5. Item 4 showed 19% were positive, and 24% remained neutral. Item 5, revealed that 96% were positive, and 4% remained neutral. There were a number of Items that remained neutral in the post-Likert survey responses, indicating that they were with-holding judgement, one way or another, and this further indicates that they were discriminating (as previously mentioned).

Research Question 2

The question was:) Based on cognitive evidence, how much did secondary school students learn when they participated in a course on modern genomic principles and practices?

The content achievement gains reported in this study, for the difference in pre-test and post-test scores, indicate that a student-centered approach with CBL can be a productive way to increase student understanding of broad-based issues in genomics. In this respect, there also is evidence that appropriate incorporation of video in genomics lessons can lead to improvements in adolescent genomic literacy (e.g., Sabatello et al., 2019), and gives further evidence of the importance of incorporating digital resources in enhancing student learning of complex topics such as those in genomics. Furthermore, there is increasing evidence that learning genetics and perhaps genomics can enhance transfer of knowledge and skills to other learning domains in biology. For example, Mead et al. (2017) showed a positive change in learning when genetics was taught first prior to teaching evolution. This not only was best for improving genetics knowledge, but also gained more content knowledge in both domains. The students were tested

Although the participants in this study began with some prior knowledge, based on their

pre-test mean scores, the pre-test mean scores were substantially lower than the post-test mean scores. For the most part, there is an expectation among researchers that participants will score relatively low on pre-test scores, with the expectation that gains on the post-test provide evidence of content achievement. For example, in the current study, the mean score on the pre-test was approximately 61 and the mean on the post-test was approximately 84, a gain of 23 score points. However, the gains for the other items was closer to 30 score points. It is important to note that some of the participants prior knowledge, as measured by the pre-test, was relatively high, but not unexpected for volunteer students in a special enriched learning program. While some pre-test scores were as high as 70 in some cases based on a 100-point score scale, 50% of the participants scored lower than 60 points.

Research Question 3

This research question addressed the following evidence. Using individual interview evidence, what are the major perceptions that the participants expressed throughout the duration of the course?

This question focused on interview evidence, namely: Using individual interview evidence, what are the major perceptions that the participants expressed throughout the duration of the course? One of the most common methods of data collection in qualitive research is the process of interviewing participants (Creswell & Poth, 2016; Slade & Sergent, 2019). By interviewing the participants in this research, it encouraged the them to freely express their understanding and misunderstanding of any genomic and/or STEM concepts, particular interests of the course, and college and career trajectory. Moreover, it provided feedback for ways to improve the course for the future.

The personal statements of the participants in response to the interview questions, and their questions throughout the duration of the course, demonstrated that they initially struggled with specific genomic and genetic concepts and processes. An excerpt from the interview with participants #s 3, 4, and 7 illustrates this confusion:

R: Throughout this course we learned and focused on polygenetic and monogenetic diseases. Was this a topic that you found interesting?

#3: Our living environment teacher doesn't go over as much as you do, and she doesn't use any websites that we used in the class. But she does explain it well but it is hard to understand it without seeing it like the way you showed us on the computer.

#7: Yea sometimes I got confused about what Mendalian traits were.

R: What do you mean?

#7: She (science teacher) doesn't really go over the location (loci) of the disease or how you can see it all over the chromosome. Like I know you told us that it isn't important to memorize chromosome number and location of the disease but it definitely helped to understand the difference between monogenetic and complex genetic (polygenetic) diseases.

R: Did you experience any confusion or difficulties with understanding polygenetic and monogenetic diseases?

#4: A little. Like why do some people have the obesity gene and others do not? I understand why some people have sickle-cell and others do not, but the complex diseases is a little hard to understand.

R: Well remember when we learned about gene mutations and people who have genetic dispositions based on their lifestyle or environment? Who remembers what a mutation is?

#4: It's the change in the DNA sequence.

R: Excellent. So, when a DNA sequence is mutated either by deletion, insertion, or substitution, the sequence is altered, causing a change in the DNA sequence.

The results and research suggests that pedagogy may have influenced the participants perceptions of the nature of scientific knowledge and scientific thinking ability, beyond acquiring content and conceptual knowledge.

Implications and Relationships to the Literature

New approaches for teaching genomic principles and practices acquired during the learning process is critical in the hopes of producing scientifically literate citizens. This research demonstrates that understanding the principles and practices of genomics by using a student-centered approach with limited lecturing, a CBL, and interdisciplinary learning, and assessment tools aimed at promoting interest in genomics can substantially influence students' critical thinking about, and interest in, important societal and scientific issues in modern genomics. The success of the *Introduction to Genomics* course can be attributed to the implementation of sufficient structured experiences in addition to more student-centered learning, such as being explicit to the participants about which skills and strategies are specifically important for progress in STEM education, introducing and utilizing scientific terminology, and encouraging student collaboration. These skills and strategies also place an emphasis on STEM careers and scientific literacy (U.S. Department of Education, 2010).

Overall the analysis of the participants responses to the Likert scale, pre-and-post-tests assessments, and interviews revealed that they expressed an increasing interest in genomic and STEM education, especially in ELSI awareness. Among the topics that the participants believed were of interest included: GINA, direct-to-consumer tests, DNA databases, reproductive issues, and newborn screening inspired them to pursue the education necessary to acclimate themselves in a scientific career. Additionally, the logical alignment of the curriculum, pedagogy, and assessment procedures that were used support the validity and reliability of the research (Prozesky, 2001). Moreover, it permitted the participants to collaborate with one another in an academic and urban setting that of which contributed to learning STEM.

Notwithstanding the rather substantial achievement gains (pre-and-post-test) and increased interest in genomics (Likert survey), some of the participants during the interview were highly responsive to discuss in what ways they were deficient in their knowledge of genomics as well as the areas where they were more proficient, as is consistent with findings from other prior research (e.g., Prozesky, 2001). Most of the participants did not have access to educational resources for learning genomics, and were not being exposed to these topics in their current schooling. Yet they demonstrated in this study, the proclivity necessary to acquire the content knowledge effectively. For example, Participant #12 attends an elite NYC public secondary school, notably one of the most prominent and selective in the county that specializes in STEM education and has a double period, college-level, semester long genetics course provided for 12th graders. The majority of the course is laboratory-based utilizing modern scientific applications including micropipetting techniques, bacterial transformation, electrophoresis, PCR, chromatography, and DNA extraction. While the course is progressive with modern principles, it is like many other science courses that exclude interdisciplinary topics such as ELSI. These interdisciplinary connections made possible with properly organized genomics lessons can connect students to the pragmatics of the real-world, and encourages them to voice their opinions and develop critical thinking skills (Dressler et al., 2014; LaRue et al., 2018; Wefer & Sheppard, 2008).

Summary of Strengths and Limitations

The development of the *Introduction to Genomics* course and curriculum (Appendix H) was designed for the duration of one year to allow secondary school students to acquire content knowledge and familiarity with modern biological principles and practices, emphasizing genomics, in a STEM college setting. Overall, the participants enjoyed CBL as it encouraged

group discussions and presentations, which helped in retaining information and improving interdisciplinary and cognitive skills. Student-centered pedagogy was generally very positive. The majority of participants stated that they preferred the BSCS 5E model as opposed to traditional/autocratic pedagogy that was typical in their schools. The report Vision and Change in Undergraduate Biology Education: A Call to Action (American Association for the Advancement of Science (AAAS), 2011) expressed great concern for an increase in more student-centered learning in undergraduate biology and science education classes. Many of the ELSI components associated with genomics were, at first, unfamiliar or seemed esoteric to them; however, exposure to these topics was very transformative, especially since many had differing critical judgements before and after the course.

There were many informal components that were implemented into the classroom, including micropipetting, DNA extraction, and AMNH laboratory techniques via weblinks. However, there were no visits to any informal learning setting such as AMNH or the Dolan DNA Center (Cold Spring Harbor Laboratories). Informal learning provides opportunities to engage students with authentic and layered learning (all ages learn different levels of content) experiences, and connect students to real-world applications. For the student, informal learning exposes them with rigorous learning opportunities beyond what they would learn in their classroom, and allows them to potentially interact with curators, researchers, and staff members (McQueen et al., 2012). Southworth et al. (2010) advocates the use of CBL to enhance genetic and biology content knowledge in the classroom. While CBL was implemented on a daily basis, there was absence of a wet lab that is also useful for conceptualizing genomic content. The course itself was not conducive to employing hands-on laboratory assignments, being that it was in a typical college classroom. Further genomics curricula, based on innovative approaches such

as the one introduced here, may be improved by including appropriately selected laboratory experiences to provide a deeper understanding of the practices of science associated with genomics research and applications (NGSS Lead States, 2013).

As a science education researcher, it is important to identify what students already know about genomics, how they represent what they know cognitively, and what experiences, if any, they already have. For example, on the first day of the course, as I have done, and continue to do in up-and-coming STEM courses, I invite comments, and ask students "What do you already know about genomics?" or "What prior knowledge do you already have associated with microbiology?" After eliciting responses and documenting them on the board, I briefly relate new information and explain some relationships to their prior knowledge and highlight the content of the syllabus. However, some students may not have any prior knowledge of the relationship between what they already know and what they will know. Therefore, it is important to include content material in the syllabus (Appendix H) that demonstrates the merging of their prior knowledge and newly acquired knowledge of the course.

Prior to the course, some of the participants had a lack of understanding of genomic relationships with other biological and scientific disciplines due to their misunderstanding of the genomics composition of the eukaryotic cell. They encountered difficulties distinguishing between polygenetic and monogenetic diseases, beneficial and harmful bacteria, inheritance, and genomic terminology. In fact, the very first question I ask participants before teaching any course related to genomics is "raise your hand if you have heard of the Human Genome Project." Based on the low number of hands raised, which unfortunately over the last several years has been less than five, there is an indication that a progressive paradigm shift in genomic education at the secondary school level is indeed essential.

Transferability. This course was developed for a select group of students from inner city schools and all were volunteers. However, this was a suitable group to examine the introduction of a new approach to biological education such as this one. It is often preferable to begin with a more tractable group of participants to initiate a novel educational experience to better establish likely boundary conditions for its transfer to other learning situations. I believe that this course can benefit colleges and secondary schools not only through dissemination of the research and experiences, but also by implementing the course as a unit or as an elective course. The course is available online at this URL: https://drawingandgenomics.wixsite.com/drawingandgenomics; as presented in Appendix B, including other interactive websites and resources that can provide biology or health educators resources to increase genomic awareness, literacy, and knowledge. While the importance of learning genomics is widely acknowledged in science and science education fields (Hood & Rowen, 2013; Wefer & Sheppard, 2008); challenges remain, especially in the ability for science teachers to apply, enhance, and implement genomic content knowledge in their classrooms, which is a major goal in science education (Banta et al. 2012; Verhoeff et al., 2009). To achieve this goal in secondary school education, schools and science teachers should enrich their students with topics that address their interests through CBL, student-centered learning, informal learning, and project-based learning.

Scalability. Students learn better by communicating through collaborating, talking, and interacting (Kovarik et al., 2013; Tanner, 2013), because each requires high levels of thinking (NRC, 1989). Teaching and or establishing a genomics course for a class greater than 30, which I have done previously in a similar academic setting, is also productive, and easily conceivable and applicable. Utilizing the pedagogical skills (as previously mentioned) encourages students to become aware of their pacing, academic responsibilities, prompts them to think more actively,

obtain more information via CBL or collaboration to clarify their new and existing knowledge (Bybee & Van Scotter, 2006). By structuring the class into groups (whether the class size is 20, 25, or 30 students) increases their potential to provide a feeling of inclusion, community, and collaboration for many students who may otherwise feel isolated in biology classrooms as noted by Tanner (2013).

Implications for Future Research

One of the challenges ahead is to offer consistent professional development for science educators and increase their awareness of the genomic era. Further research is needed at the middle and secondary school level to implement and identify the factors that promote students' interest, engagement, discussion, and achievement in genomics education. Once these factors are identified, it is up to the school and/or school district to effectively implement policies that promote genomic education.

Future research expanding from this course and study would provide access and exposure to increase genomic awareness throughout secondary schools and assist in establishing more (b/c there are other secondary schools that teach genomics) courses and/or units to the current biology and health curriculum. The data and information extrapolated from the research can serve as a guide to develop, implement, and expand future secondary school courses that encourage student-centered, collaborative, and interdisciplinary learning.

In this research, one of the aims was to enhance the participants broader understanding of the interdisciplinary nature of genomics, so eventually through these experiences, secondary school students could understand and increase their level of biological, STEM and human health content knowledge. This, in turn, is expected to support their development of scientific literacy, college and career readiness, ELSI awareness, and interdisciplinary skills. Since genomics has a

myriad of pragmatic benefits, individually and globally, that of which, so many science researchers, science teachers, and administrators consistently debate on and hope to improve with science education in k-12 classrooms (NRC, 1989) it would ideal to implement a genomics program or lesson unit into the science curriculum to keep students up-to-date with modern aspects of science. This is also a goal of other researchers in the field of science education (e.g., Carver et al., 2017; Dougherty et al., 2011; Sabatello et al., 2019; Wefer & Sheppard, 2008; and others as mentioned previously), who have been very successful in integrating genomics into their research and pedagogy. Not only does genomics allow scaffolding of interdisciplinary science domains (as previously mentioned) it draws attention to important connections that are not often found across the science curriculum, such as ELSI. Given the success of this initial study, I anticipate to continue with designing, developing, and consistently improving the foundational curriculum and pedagogy of this and other genomic and STEM courses.

Professional Development

Considering the number of professional development courses, training, and academic resources that many science teachers have access to, and are required to fulfill, more effort is needed to make them truly transformative as suggested by Bybee.

> Many secondary schools are preparing and supporting teachers to transform how our students think, engage, collaborate, and problem solve to prepare them for college and future the workforce. From a teacher's standpoint, they would need to have available resources, professional development (PD), time management, and planning to assess student performance. From a student's standpoint "students can develop 21st Century skills such as adaptability, complex communication, social skills, nonroutine problem solving, self-management/self-development, and systems thinking. (Bybee, 2010, p. 31)

However, many states have yet to be progressive with introducing and implementing cutting edge biology research in the science classroom. The opportunity to include and implement modern topics in genomics and computer-based learning experiences associated with

biology, should be promoted and applied into the science classroom. Many states have adopted certain standards that may seem advanced or rigorous. However, the majority of teachers across the nation are still teaching students how to pass a mandated-state test; and too often, these contain little or no emphasis on core ideas of genomics a step in the right direction. If a school or district truly wants to address advanced scientific research in the classroom, a paradigm shift from mandated-state testing of student content knowledge, to what are students interested in, a sufficient portion of these mandated-state tests have biological concepts that require students to simply memorize facts. Progressive teachers that are interested in advancing themselves as well as their students have a limited autonomy as to what can be taught. Not only does this affect scientific literacy and the nature of science it limits a student's level of scientific engagement with modern science. Most advanced learning in the biological sciences exists in afterschool programs and informal settings; which is a step in the right direction. If a school or district truly wants to address advanced scientific research in the classroom, a paradigm shift from mandated-state testing of student content knowledge, to what are students interested in, researching, developing, and hopefully cultivating themselves in, needs to occur. For some science teachers, there is no incentive to take-part in a professional development course that addresses advanced and/or modern scientific topics. Perhaps it does not correlate with the existing curriculum, students are not suitable to learn these types of topics, or learning new content material may be intense and/or intimidating for some teachers. Because learning is a never-ending process, it is plausible to think that it may be overwhelming for some teachers to acquire new content knowledge to implement into their class. However, collaborating with the professional development network will support the growth of a teacher, school community, and practices. It would be beneficial if more than two science teachers attended professional development so they

can coexist by encouraging each other to better understand content material, develop strategies for teaching, and troubleshooting with any procedures, as this will alleviate frustration.

The NWABR's professional development workshops are grounded on principles that are logical with educational research pertaining to adult learning. For example, NWABR implements cognitive traits (awareness, engagement, self-efficacy, and relevance) into their professional development in order to improve science teachers current content knowledge and pedagogical skills while providing engaging and varied opportunities to practice new skills and receive feedback about progress (Kovarik et al., (2013). These principles are developed upon the teacher's prior and current knowledge and pedagogical skills and "provides engaging and varied opportunities to practice new skills and receive feedback about progress. Successful professional development should result in measurable increases in teacher knowledge and skills that are linked to outcomes in student achievement." (Kovarik et al., 2013, p. 444)

Conclusion

By engaging secondary school students in a modern genomics course as documented here, they were given the opportunity to develop more concise knowledge and critical thinking skills about a unique STEM domain, while learning how to engage in science that is contemporary and applicable to real-life/real-world issues. Given that the current curriculum in science classes reflects domains in science that are relatively out-of-date, it is important for students to engage in science that reflects cutting-edge discoveries including, personalized medicine and direct-to-consumer; and domains in science that have an application to real-life phenomena. Genomics offers this type of real-life/real-world applications that encourage all students at all academic levels to conceptualize genomic diseases, medicine, ethics, beliefs, research, and careers.

The results of this research showed that genomic curricular materials and resources are, in fact, available and improving to include issues addressing individualization and society. In addition, this research focused on using CBL and interdisciplinary science learning, as well as, diverse and innovative teaching (Tanner, 2013; Bybee & Van Scotter, 2006), and assessment strategies. While the clear benefits of teaching genomics has been well-supported throughout this research, the continuation of integrating aspects of genomics into to the majority of secondary school curricula has yet to be implemented into science classrooms. Since genomics and genetics both have foundational science and real-life/real-world applications, the content is well-grounded to be integrated in an interdisciplinary way with other foundational sciences, especially STEM courses. Moreover, learning genomics encourages students to become aware of modern medical advancements (Molster et al., 2018); and it is necessary and beneficial for genomics to be incorporated into to secondary schools (Dressler et al., 2014; LaRue et al., 2018; Sabatello et al., 2019; Wefer & Sheppard, 2008).

Currently, medical, nursing, pharmacology, and other human health programs are gradually exposing students to a curriculum that introduces them to genomic principles and practices (as previously mentioned). As science educators, it is our obligation to inform the next generation of future scientists to be knowledgeable in genomics so they can transform new information and discoveries into scientific practice.

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Appendix A

Institutional Review Board Approval, Teachers College

TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Teachers College IRB Exempt Study Approval

To: Adam Stefanile
From: Myra Luna Lucero, Research Compliance Manager

Subject: IRB Approval: 20-169 Protocol Date: 01/10/2020

Thank you for submitting your study entitled, "*A Study of Secondary School Students' Participation in a Novel Course on Genomic Principles and Practices*;" the IRB has determined that your study is Exempt from committee review (Category 4) on 01/10/2020.

Please keep in mind that the IRB Committee must be contacted if there are any changes to your research protocol. The number assigned to your protocol is 20-169. Feel free to contact the IRB Office by using the "Messages" option in the electronic Mentor IRB system if you have any questions about this protocol.

As the PI of record for this protocol, you are required to:

Use current, up-to-date IRB approved documents
Ensure all study staff and their CITI certifications are on record with the IRB Notify the IRB of any changes or modifications to your study procedures Alert the IRB of any adverse events

You are also required to respond if the IRB communicates with you directly about any aspect of your protocol. Failure to adhere to your responsibilities as a study PI can result in action by the IRB up to and including suspension of your approval and cessation of your research.

You can retrieve a PDF copy of this approval letter from Mentor IRB. Best wishes for your research work.

Sincerely,
Dr. Myra Luna Lucero Research Compliance Manager IRB@tc.edu

Appendix B

Genomic Educational Resources and Interactive Websites

Citizen Science/Games	
Foldit	https://fold.it/portal/
Eterna	http://www.eternagame.org/web/
Phylo	http://phylo.cs.mcgill.ca/
Colleges and Universities	
Harvard University, Personal Genetics Education Project	https://pged.org/mission/
Johns Hopkins University	https://www.omim.org
University of Utah Genetic Science Learning Center	http://learn.genetics.utah.edu
Washington University in St. Louis	https://schoolpartnership.wustl.edu/instructional-materials/modern-genetics/
Museums and Nonprofit Websites	
American Museum of Natural History	https://www.amnh.org/explore/videos
American Society for Microbiology	http://www.asm.org/index.php/in-the-classroom#k12
American Society of Human Genetics	http://www.ashg.org/education/K12.shtml
Dolan DNA Center (Cold Spring Harbor Laboratories)	https://www.dnalc.org/resources/
Education Development Center	http://www2.edc.org/weblabs/
Howard Hughes Medical Institute	http://www.hhmi.org/biointeractive
Smithsonian National Museum of Natural History	https://naturalhistory.si.edu
National Institutes of Health and other federal resources	
BLAST, NCBI, NLM	https://www.ncbi.nlm.nih.gov/blast/
Gene Ed, NLM, National Human Genome Research Institute (NHGRI)	https://geneed.nlm.nih.gov/
Genetics Home Reference, NLM	https://ghr.nlm.nih.gov/
National Human Genome Research Institute (NHGRI	https://www.genome.gov/
Rare Diseases and Genetic Information Center	https://rarediseases.info.nih.gov

Appendix C

Likert-Scale Survey Items

Background Questionnaire

Your Opinions About Learning Modern Genomics and Genetics

Section 1: Background information

Please mark with an X the appropriate answer:

I-What is your age?

- ☐ 13-14
- ☐ 15-16
- ☐ 17-18
- ☐ 18 or older

II-What is your gender?

- ☐ Male
- ☐ Female

III-What was the year that you began high school? _____

Directions

Mark the answer below each statement that best represents your response to the statement.

1. I believe it is important for students like me to learn about genetic/genomic diseases.

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

2. In my opinion, I think learning genomics/genetics will improve my understanding of other courses such as biology, human health, and related sciences.

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

3. Based on what I know, I believe that the environment affects a person's genome (that is, all of a person's genes).

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

4. It is important to study genomics/genetics, because these ideas are increasingly important in ethical, legal, and social aspects of human societies.

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

5. I believe that learning the factual concepts and processes of genomics improve my learning in college and better prepare me for a career in the field of science and/or medicine.

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

Directions

Below are statements and questions to read and think about. After reading each one, look at the answers below it and select one that you believe is the best one based on your opinion. If you disagree, mark one of the responses that has a 'no.' If you agree, then mark one of the responses that has a 'yes.' Sometimes, we have no definite opinion, then it is OK to mark Unsure.

1-If a person has genes that cause illness, is it acceptable to require that they undergo a treatment to try to correct these genes so the bad genes will not be passed on to future generations?

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

2-Our genes appear to determine how long we can live. In your opinion should a medical scientist be allowed to alter the genome of a baby before birth to enhance its eventual length of life?

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

3-It is even possible eventually to alter the genes of a mature human being to increase the person's length of life. If the person wanted their genes to be altered to increase their lifespan would you approve of doing it?

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

4-It is possible to identify the genes of a human fetus before it is born including those causing diseases of the baby. Would you support research to find out how to correct a baby's genes before it is born to improve its health?

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

5-Modern genetic research has discovered that humans are related to extinct pre-humans known as Neanderthals, and thus helped us to better understand our origins. However, this is expensive research. In your opinion should our government use taxes to help support this kind of research?

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

Directions

Please read each statement below, and then mark the response that you believe best represents your opinion using this set of statements.

1-If we can improve the human genome through medical research, scientists should be given freedom to try to do so.

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

2-Someday, parents should be able to choose whether the mother will give birth to a boy or a girl through new knowledge gained in modern genetic research.

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

3-Using modern techniques of engineering, we should encourage engineers to develop microscopic robots that can enter our cells to examine and correct errors in our human genes.

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

4-Currently the United Kingdom has established a National DNA Database (NDNAD). This database has the DNA profiles and samples from a select number of UK individuals. Regardless of why this database exists, the United States should develop a National DNA Database.

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

5-Polygenetic diseases are rarely taught in the majority of high schools across the nation. Yet most of these diseases including cancers, cardiovascular, respiratory, and neurological diseases affect many individuals. Polygenetic diseases should be taught more frequently in science and health classes.

1	2	3	4	5
Completely disagree	Disagree	Neutral	Agree	Completely agree

Appendix D

Introduction to Genomics Multiple-Choice Content Achievement Test.

Directions: Circle one answer that you think is the best for each of the 25 multiple-choice question below.

1. The genetic components of humans are located in the?

(A) cytoplasm
(B) nucleus
(C) plasma membrane
(D) centrioles

2. Which of the following determines gender?

(A) autosomes
(B) chromosomes
(C) sex chromosomes
(D) DNA

3. Genes are located on?

(A) DNA
(B) nucleotide
(C) nucleus
(D) chromosomes

4. Chromosomes 1-22 of a human represent

(A) sex cells
(B) autosomes
(C) haploid
(D) diploid

5. Normal women possess this type of chromosome

(A) XX
(B) XY
(C) XYY
(D) XXYY

6. Which of the following are alternate forms of a gene?

(A) autosomes
(B) chromosomes
(C) alleles
(D) nucleus

7. Which of the following terms describe visible physical features of an organism?
(A) Aneuploidy
(B) mutation
(C) genotype
(D) phenotype

8. An organism that has two (2) **of the same** alleles is referred to as
(A) genotype
(B) heterozygous
(C) phenotype
(D) homozygous

9. An organism that has two (2) **different** alleles is referred to as
(A) genotype
(B) heterozygous
(C) phenotype
(D) homozygous

10. A person born with a dominant disease involves damage to only
(A) one gene
(B) multiple genes
(C) both genes from both parents
(D) one gene from one parent

11. Which of the following best describes the Human Genome Project?
(A) a detailed map of all the genes in a human
(B) a record of how humans evolved
(C) compares humans to apes
(D) compares humans to closely related animals

12. Since the completion of the Human Genome Project, there have been many "major breakthroughs" in biology and human health. Which of the following would NOT be considered a "major breakthrough" since completing the Human Genome Project?
(A) polymerase chain reaction
(B) DNA base paring
(C) DNA sequencing
(D) electrophoresis

13. Genome-wide association study (GWAS) is a technique that involves rapidly scanning markers across an individual' genome to find genetic variations associated with:
(A) genes
(B) DNA
(C) dominant and recessive traits
(D) diseases

14. What percentage of bacterial organisms cause disease to humans?
(A) 1-5%
(B) 10-15%
(C) 15-20%
(D) 20-25%

15. The Human Microbiome is involved with
(A) bacterial organisms in the human body
(B) biological diversity
(C) macroscopic organisms in the human body
(D) abiotic factors to improve human life

16. Which factors **mostly** influence the Human Microbiome?
(A) alcohol and drugs
(B) age
(C) ethnicity
(D) diet

17. Which of the following topics is associated with ethical, legal, and social issues of genomics?
(A) discrimination
(B) ethnicity
(C) pregnancy
(D) college admissions

18. Genetic Information Nondiscrimination Act (GINA) was passed into law, prohibiting discrimination by ALL of the following except
(A) government agencies
(B) health insurance
(C) employers
(D) hospitals

19. Pharmacogenomics is a combination of two specific fields of science: "pharmacology" and "genomics". Which terms are best related to pharmacogenomics?
(A) DNA and the cost of medicine
(B) DNA and drug response
(C) DNA and metabolic rate
(D) DNA and protein synthesis

20. People process and respond differently to medicine because
(A) of the cost
(B) of their age
(C) of the time of the day
(D) of their genomes

21. A genetic disease/disorder is a result of a change in an organism's
(A) cellular components
(B) metabolic rate
(C) disease
(D) DNA sequence

22. Polygenetic trait is one whose phenotype is influenced by
(A) one gene
(B) more than one gene
(C) ethnicity
(D) race and ethnicity

23. Most traits and diseases in humans and in many organisms are polygenetic. Which of the following is a polygenetic disease?
(A) cystic fibrosis
(B) sickle-cell anemia
(C) breast cancer
(D) Huntington's disease

24. Karyotype, pedigree, phylogenetic tree, and the human genome are examples of:
(A) DNA mutations
(B) DNA analysis
(C) diagrams and illustrations
(D) DNA sequences

25. Sex linked traits and diseases are
(A) located on sex chromosomes
(B) occur only in males
(C) located on autosomes
(D) altered through DNA sequence

Appendix E

The National Science Education Standards (NSES).

Table 1.1: LIFE SCIENCE STANDARDS

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Characteristics of organisms	Structure and function in living systems	The cell
Life cycles of organisms	Reproduction and heredity	Molecular basis of heredity
Organisms and environments	Regulation and behavior	Biological evolution
	Population and ecosystems	Interdependence of organisms
	Diversity and adaptions of organisms	Matter, energy, and organization in living systems
		Behavior of organisms

Table 1.2: SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

LEVELS K-4	LEVELS 5-8	LEVELS 9-12
Personal health	Personal health	Personal and community health
Characteristics and changes in populations	Populations, resources, and environments	Population growth
Types of resources	Natural hazards	Natural resources
Changes in environments	Risks and benefits	Environmental quality
Science and technology in local challenges	Science and technology in society	Natural and human-induced hazards
		Science and technology in local, national, and global challenges

Appendix F

Chart of Research Questions and Sources of Data

Research Questions	**Sources of Evidence**
1. Based on affective evidence, how did secondary school students perceive and critically judge, content topics learned in a course on modern genomic principles and practices?	Pre-test and Post-test for cognitive outcomes Paired t-test Descriptive statistics
2. Based on cognitive evidence, how much did secondary school students learn when they participated in a course on modern genomic principles and practices?	Likert-scale survey Descriptive statistics, tabular data, bar data
3. Using individual interview evidence, what are the major perceptions that the participants expressed throughout the duration of the course?	Individual structured interview narrative Thematic analysis

Appendix G

Structured Interview Questions

Interview question 1. Please tell me, what were some interesting topics that you learned throughout the duration of the course?

Interview question 2. Throughout this course we learned and focused on polygenetic and monogenetic diseases. Was this a topic that you found interesting?

Interview question 3. Did you enjoy utilizing CBL throughout the course?

Interview question 4. Were there any particular topics that you enjoyed learning regarding ELSI?

Interview question 5. Did this course help you with any college or career choices in genomics and/or STEM?

Appendix H

Introduction to Genomics Syllabus

COURSE BACKGROUND/DESCRIPTION

The National Institute of Health: National Human Genome Research Institute defines genomics as "the study of the entire genome of an organism whereas genetics refers to the study of a particular gene." *Genomics* is generally referred to as the study of the content, structure, organization, and functioning of an organisms' genome. It is also concerned with the material contained in the genome that composes an organism and the analysis of multiple genes that interact with each other. However, *genetics* refers to the study of a singular gene of an organism. This course introduces students to the basic principles and practices of genomics/genetics, human health, and STEM concepts. Lecture topics include: basic genomic and genetic structure, function, and terminology, the Human Genome Project (HGP), genomics and medicine, genomics and evolution, microbial genomics, and genomics and ELSI.

Knowledge and Performance Objectives: Students will understand the following principles and practices of genomics:

1. **Genomic and Genetic Principles.** Students will develop their knowledge of foundational genetic/genomic principles and processes and the interdisciplinary sciences that are associated with

2. **Analyzing DNA.** Discussing the molecular details of DNA and RNA, utilizing online genetic sequences to understand the basic concepts of DNA sequencing and the BLAST computer tool.

3. **The Human Genome Project (HGP).** Discussing and highlighting the significant goals and objectives of deciphering the chemical makeup of the entire human genetic code/ genome. This includes: identifying the genes involved in both rare and common diseases, assess the ethical, legal, and social implications of new genetic technologies, and to educate the public about these issues.

4. **Genomics and Medicine.** Describe the fundamental concepts of medicine and diseases, how the human body responds to environmental factors and treatments of medication, and introduce pharmacogenomic principles.

5. **Genomics and Evolution.** Explain the purpose and significance of phylogenetic trees and their association to genomes, compare the relationship of humans and other close and distant organisms, and visualize how humans geographically evolved.

6. **Microbial Genomics.** Comparing the sequences of bacterial genomes using online genome databases, exploring the beneficial and harmful bacterial species *in* and *on* our bodies, and around our house. We will dispel certain misconceptions pertaining to bacteria and emphasize the importance of the human microbiome (HMB).

7. **Genomics and Ethics (ELSI).** Listing and elaborating the ethical principles involving genomics and current issues that face individuals, society, and law and government.

METHOD OF INSTRUCTION

The objectives will be met through:

1. Individual assignments (including assigned readings, presentations, written assignments)

2. Lectures, computer based-learning, and utilizing interactive learning technology/websites, with a focus on genomics, biology, and human health.

Lecture Schedule

Session and Topic

Unit 1: Genomics and Genetics

Session 1: Course overview and Introduction to Genomics

Course expectations and the syllabus will be explained in detail. An explanation of interdisciplinary learning, computer-based learning, student and collaborative learning, and its relation to genomics, STEM, biology, and human health.

Lecture will emphasize definition and principles of genomics and genetics, landmarks and timeline of genomic discoveries, and human health benefits associated with genomics.

Session 2: Basic Genetics and (Mendelian Traits and Sex Linkage)

Understanding the basic principles of human genomics and genetics and the role of genes, human life style, and the environment is essential for understanding and applying genomic and genetic processes.

Session 3: Structure and Function of Chromosomes

In eukaryotic cells, genetic information in the form of DNA, is condensed in the nucleus, and is divided between a set of different chromosomes. Genes are the units of inheritance located on specific sections, loci on chromosomes. Additionally, we will discuss the proteins involved in packaging the DNA, and how chromosomes are also associated with many proteins required for the processes of gene expression, DNA replication, and DNA repair.

Session 4: Patterns of Inheritance

Describe the basic laws of inheritance: chromosomes 1-22 or X and Y, dominant and recessive, and emphasize importance of karyotype, Punnett square, and pedigree visuals in order to understand patterns of traits and disease transmission. The five basic types of inheritance are single-gene diseases: autosomal dominant, autosomal recessive, X-linked dominant, X-linked recessive, and mitochondrial.

Unit 2:Analyzing DNA

Session 5: Nucleotides and Nitrogen Bases

DNA is composed of only four basic molecules called nucleotides; the four bases are adenine, guanine, cytosine, and thymine. Two of the bases, adenine and guanine, are similar in structure and are called **purines**. The other two bases, cytosine and thymine, also are similar and are called **pyrimidines**. DNA is a double helix composed of two strands of nucleotides held together by **phosphodiester bonds**,

Session 6: DNA Sequencing

Using the following website: https://blast.ncbi.nlm.nih.gov/Blast.cgi we will understand the concept and utilization of Basic Local Alignment Search Tool (BLAST) to map RNA and/or DNA sequences to see the genomic relationships of various organisms.

Unit 3: The Human Genome Project

Session 7: The Human Genome Project: The First Draft (2001)

The Human Genome Project (HGP) was an international collaborative effort to analyze and document all of the human genes (genome) for the benefit of documenting the *loci*, disease, and genotype of humans. We will discuss the essential concepts and important goals of the HGP.

Session 8: Today's Human Genome Project

Scientists have sequenced the entire human genome, which contains 3 billion nucleotides. Terms including "personalized medicine" and "personal genomics" is now quite common in the scientific community. We will discuss how genomic research has been conducted from epidemiological studies that previously described the human health and/or disease conditions in a particular population.

Session 9: Genome Wide Association Studies (GWAS)

To identify the genes involved in human diseases, we will learn how to explore, explain, and elaborate the concepts of GWAS using the following website: https://www.ebi.ac.uk/gwas. Identifying the specific loci of genes that are markers for genomic diseases, we will pinpoint genes that may contribute to a person's risk of developing a certain disease including

monogenetic, polygenetic, autosomal, and sex-linked diseases. Using GWAS, we will search the website for genomes that have small variations, called single nucleotide polymorphisms or SNPs, that occur more frequently in people with a particular disease than in people without the disease

Unit 4: Genomics and Medicine

Session 10: Introduction to Center for Disease Control and Prevention (CDC)

We will become learn how to utilize, explore, and obtain scientific data from the CDC website. As you begin as novices, you will eventually become proficient with demonstrating how to utilize the CDC website entirely and eventually present you interest and data to the rest of the class. Additionally, we will learn the cellular organelles of the eukaryotic and bacterial cell and compare and contrast the two cells and cellular organelles.

Session 11: Monogenetic and Chromosomal Diseases

List and briefly explain the common monogenetic and chromosomal diseases, and become familiar with the loci of these diseases that are on specific chromosomes. In addition, we will view the SNPs of each of the monogenetic and chromosomal diseases to better understand the molecular concepts of DNA sequences and genomic disease.

Session 12: Polygenetic/Complex Genomic Diseases

List and briefly explain the polygenetic diseases, and become familiar with the loci of these diseases that are on specific chromosomes. Comparing normal and abnormal genes to compare the SNPs will be used to conceptualize the benefits of using modern genomic technology for determining the loci of a genomic disease.

Session 13: Pharmacogenomics

Define and describe the term and benefits of pharmacogenomics/tailored medicine. We will emphasize the purposes of whole genome sequencing and its relationship to pharmacogenomics/tailored medicine while discussing the ethical aspects of this modern form of medicine.

Unit 5: Genomics and Evolution

Session 14: Tree of Life

In this session we will view a define and view the principles of a phylogenetic tree, illustrating the relationship of several species by showing their commonalities, close and distant resemblance, and ancestors and descendants.

Session 15: Phylogenetic Trees

By viewing a phylogenetic tree, we will be able to list and describe the morphological/anatomical information, behavioral information, and molecular information to analyze four different species of plants. We will understand how a DNA sequence that has a close resemblance to sequences may will have different physical features.

Session 16: Neanderthals

In this session, we will define and discuss the evolutionary aspects of human and closely related species and elaborate the changes that can occur between species during the evolutionary process. We will compare the *Homo sapiens*, *Homo neanderthalensis*, the Denisovan human, and *Pan troglodytes*' organisms to conceptualize their evolutionary linage.

Session 17: Chromosome and Ancestry Painting

Using a modern approach to visualize the genetic ancestry of humans, ancestry painting is used to illustrate the ancestry composition of populations and individuals. We will look at the loci of genes to view similarities of *Homo sapiens* and their geographic origin.

Unit 6: Microbial Genomics

Session 18: Microbial and Human Genomes

We will list and view the different bacterial species that exist *in* and *on* our body and look at their genomes and compare them with other harmful bacterial species. In addition, we will use the CDC website to analyze and document the harmful microbes that are present on our body.

Session 19: Microbiome *on* Our Body

Listing and categorizing the microorganisms of the human normal flora, we will discuss the human microbiome in human health and disease, and discuss the pros and cons of probiotics on human health, the microbiome–nutrient interaction and the role of vitamins in promoting the selective growth of microbes in the digestive and other systems, as well as determinants of the development of a healthy microbiome.

Session 20: Microbiome *in* Your Mouth

Oral microbiomes has an important role in the human microbial community and human health. We will use the Human oral microbiome database (HOMD) website to better understand the description of a human-associated microbiome and the role of the microbiome in health and disease. We will also compare the oral microbiome of other animals to understand how different bacterial organisms live in different animals.

Session 21: Microbiome *around* Your House

Learning about the common surfaces that bacterial species occupy are important for public health. Various bacterial species reside in the bathroom, on our toilets; in the kitchen in our refrigerators, are the major means of some infectious disease occurrences. We will list and describe some of the common bacterial species that live throughout our home and the general background of the household microbiota.

Unit 7: Genomics and Ethics

Session 22: Ethical, Legal, and Social Implications (ELSI)

We will establish some of the ethical principles involved in science research and genomics, and then list, elaborate, and provide the pros and cons of the current ELSI topics that have, and continue to be, a challenge in science research and genomics.

Session 23: Genetically Modified Organisms (GMOs)

Genetically Modified Organisms (GMOs) are developed by inserting a genome from an organism such as an animal, plant, fungi, bacteria, and virus; into usually unrelated species. Biotechnology has allowed scientists the ability to overcome insurmountable physiological barriers and to exchange genetic materials among all living organisms.