INVESTIGATING THE ROLE OF CONTENT KNOWLEDGE, ARGUMENTATION, AND SITUATIONAL FEATURES TO SUPPORT GENETICS LITERACY

By

NICOLE ANNE SHEA

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ABSTRACT OF THE DISSERTATION

Investigating the role of content knowledge, argumentation,

and situational features to support genetics literacy

by NICOLE ANNE SHEA

Dissertation Director: Ravit Golan Duncan

Science curriculum is often used as a means to train students as future scientists with less emphasis placed on preparing students to reason about issues they may encounter in their daily lives (Feinstein, Allen, & Jenkins, 2013; Roth & Barton, 2004). The general public is required to think scientifically to some degree throughout their life and often across a variety of issues. From an empirical standpoint, we do not have a robust understanding of what scientific knowledge the public finds useful for reasoning about socio-scientific issues in their everyday lives (Feinstein, 2011). We also know very little about how the situational features of an issue influences reasoning strategy (i.e., the use of knowledge to generate arguments). Rapid advances in science - particularly in genetics - increasingly challenge the public to reason about socio-scientific issues. This raises questions about the public's ability to participate knowledgeably in socio-scientific debates, and to provide informed consent for a variety of novel scientific procedures. This dissertation aims to answer the questions: *How do individuals use their genetic content knowledge to reason about authentic issues they may encounter in their daily lives?* Individuals' scientific knowledge is a critical aspect of scientific literacy, but what scientific literacy looks like in practice as individuals use their content knowledge to reason about issues comprised of different situational features is still unclear. The purpose of this dissertation is to explore what knowledge is actually used by individuals

to generate and support arguments about a variety of socio-scientific issues, and how the features of those issues influences reasoning strategy. Three studies were conducted to answer questions reflecting this purpose. Findings from this dissertation provide important insights into what scientific literacy looks like in practice.

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Chapter 1: Introduction

1.1 Statement of the Problem

Supporting the public's engagement with science in everyday life is an important goal of science education initiatives (AAAS, 2011; NRC, 2011). The general public is required to think scientifically to some degree throughout their life and often across a variety of issues. However, we do not yet know how individuals use such knowledge to reason and make informed decisions about a variety of issues they may encounter. The purpose of this dissertation is to address research questions investigating how individuals use their knowledge of genetics to reason about authentic genetics issues.

Findings from this work provide a more nuanced understanding of scientific literacy in two ways. First, by unpacking the interaction of content knowledge, argument generation, and the role of situational features of a reasoning task to determine how these components impact reasoning about socio-scientific issues - a core aspect of scientific literacy. Socio-scientific issues "represent controversial social issues with conceptual, procedural, or technological ties to science" (Sadler & Donnelly, 2006, p. 1463). Thus, findings from this work provide clarity as to the meaning of scientific literacy, particularly in the domain of genetics. Individuals' scientific knowledge (Horst, 2007) is a critical aspect of scientific literacy, but what is still unclear is what scientific literacy looks like in practice as individuals use their content knowledge to reason about issues comprised of various situational features. This dissertation seeks to clarify this issue by exploring how individuals use their knowledge of genetics to generate arguments across a variety of issues.

Second, findings from this study shed light on what knowledge is actually used by the public to reason about socio-scientific issues. It is possible that individuals may

reason quite effectively without expert level knowledge in the domain (Irwin & Wynne, 1996). "False conceptions of the public operate among scientists and in policy making, that is deficit concepts of the public, and these misguide communication efforts and interventions and alienate the public still further" (Bauer, 2009, p. 225). Thus, it is important to determine how individuals reason about socio-scientific issues in order to elucidate what scientific literacy means today. This dissertation sought to empirically test how individuals with varying levels of genetic knowledge reason about genetics issues, thus exploring what the public knows and needs to know in order to generate sound arguments about such issues.

Various conceptions of scientific literacy are described in the research literature. Many describe why scientific literacy is important for individuals to develop and how such literacy supports reasoning about socio-scientific issues. However, we currently know very little about the kinds of socio-scientific issues individuals will likely encounter in their lives and the kinds of domain-specific knowledge required to reason about such issues. Conceptions of scientific literacy are shifting with the advancement of science and its accessibility to the public. Thus, understanding what factors contribute to the development of scientific literacy in modern society is important for supporting effective and meaningful science education initiatives that promote lifelong civic engagement with science.

1.1.1 Views on scientific literacy.

There are currently several ways in which scientific literacy is defined, many of which include notions of knowledge in use (Ryder, 2001). Paul Hurd initially popularized the term scientific literacy in 1958 and later provided his definition as “a civic

competency required for rational thinking about science in relation to personal, social, political, economic problems, and issues that one is likely to meet throughout life" (Hurd, 1998, p. 410). As the notion of scientific literacy developed, Roberts (2007) contributed two broad perspectives on its meaning, that he termed Vision I and Vision II. Vision I focuses on what individuals need to know or do in order to be considered scientifically literate (i.e., notions outlined by education reform initiatives, such as *Project 2061* (AAAS, 2001)), while Vision II focuses on what science literacy looks like in action (i.e., how scientific knowledge is used to reason about problems encountered in daily life). These descriptions of scientific literacy hold in common the need for scientific knowledge and use of such knowledge to reason about authentic scientific issues.

Recently, the National Research Council (NRC, 2012) developed a framework to guide the formulation of next generation science standards. Ascribing to Robert's (2007) Vision I of scientific literacy, the framework focuses on three specific dimensions describing knowledge of disciplinary core ideas, scientific practices, and cross-cutting themes. These three dimensions focus on what students should know in science domains (core ideas), how these ideas relate to what scientists do (practices), and the coherence of disciplinary knowledge using organizational schema (cross-cutting themes) (NRC, 2012). This framework is based on several prior educational reform efforts including *NSES, AAAS Benchmarks, NAEP*, and *Science College Board Standards for College Success*, as well as multiple veins of research that detail best practices in science learning and teaching.

The NRC's effort to provide a framework to guide the revision of science standards demonstrates one means for defining scientific literacy and preparing students

for civic engagement. However, other avenues for defining scientific literacy have also proven fruitful. Noah Feinstein (2011, 2013) challenges popular views of scientific literacy by suggesting that researchers and practitioners have long interpreted this term to mean the level of scientific knowledge one needs in order to participate in modern life. He counters this notion by suggesting we must also consider how individuals find science useful (i.e., how members of the public actually use science in their everyday lives) for reasoning about socio-scientific issues they encounter. By usefulness, Feinstein means the ways in which "science education can help people solve personally meaningful problems in their lives, directly affect their material and social circumstances, shape their behavior, and inform their most significant practical and political decisions" (Feinstein, 2011, p. 2). According to Robert's (2007) Vision II, such usefulness and the consequent use of scientific knowledge, is the heart of what it means to be scientifically literate (Feinstein, 2011).

Very few educational initiatives consider how knowledge of science relates to everyday situations throughout individuals' lives. One example is the Programme for International Student Assessment (PISA), an Australian-based assessment that includes reading, mathematics, and science literacy emphases. The science literacy component of the assessment embodies Robert's (2007) Vision II for scientific literacy by testing students' science knowledge as they reason about authentic issues they may encounter, such as health care decisions, environmental protection issues, and use and distribution of natural resources, etc. (Bybee, Fensham, & Laurie, 2009). PISA defines scientific literacy as individuals' ability to "identify scientific issues, explain phenomena scientifically, and use scientific evidence as they respond to the situation" (Bybee, Fensham, & Laurie,

2009, p. 863). Not unlike the NRC's (2012) framework for next generation science standards, PISA also places emphasis on what students need to know about science in a rapidly changing society. However, PISA considers scientific literacy as extending beyond what students know, to how they apply such knowledge when considering socio-scientific issues prevalent in society.

1.1.2 Shared scientific literacy.

The conceptions of scientific literacy discussed up to this point consider the literacy of individual members of society. However, it is important to note that some researchers also consider scientific literacy to be collective in nature (i.e., scientific literacy is measured across a community, not ascribed at the individual level). Roth and Lee (2002) offer such a description with their ethnographic study of the Henderson Creek Project of the Pacific Northwest where a variety of experts, community members, and school children collaborated to determine the quality of their drinking water and how to improve its overall stability. The objective of this study was to challenge the traditional definition of scientific literacy as an individual, measurable, and school-based phenomenon, in order to focus instead on one that relies on collective knowledge across a variety of individuals. Roth and Lee (2002) apply a salient analogy of the fiber and thread to describe their conception of this form of scientific literacy: “A collective activity is analogous to the thread, and individual contributions are no more than the individual fibers. In this way, scientific literacy is always achieved by a collective entity rather than being an individual property” (p.36). They go on to add that, “it is impossible to derive the concrete properties of each fiber (individual) from the thread or infer the properties of the thread from the properties of an individual fiber” (p.36).

Following the fibers and thread analogy, Roth and Lee provide examples from their study to demonstrate how, in a community project, a variety of people with different levels of scientific knowledge contributed to the understanding of the issue (i.e. water quality). This notion of scientific literacy as a collective praxis subscribes to Lave and Wenger's (1991) description of communities of practice where community members living in the area for many years and experts in water treatment could be considered "full participants" and the lay public and middle school students contributing to data collection could be considered "legitimate peripheral participants". As Lave and Wenger describe, in a community of practice the full participant is not more important that the legitimate peripheral participant. Each individual plays a contributing role in the community of practice and in this case, their participation raises the collective scientific literacy of the group. Therefore, as stated by Roth and Lee (2002), scientific literacy in this case cannot be derived from any one individual, but instead is the result of the activity taking place within the collective community. The authors further note that, "the scientific literacy that emerges as the thread of the conversation could not be predicted from the scientific literacy of the individual participant… scientific literacy in conversational interaction is an irreducibly social phenomenon" (Roth & Lee, 2002, p. 39). If we buy into the notion that scientific literacy is a collective praxis, this would imply that it is not essential for all individuals to become experts or full participants in the community. "Rather, it is sufficient that such knowledge and practice exists within a collective body, in which members have a commitment to open and truly democratic dialogue" (Roth & Lee, 2002, p. 51).

However, “truly democratic dialogue” is essentially nonexistent when it comes to making decisions within a community. Usually there are political drivers that override the dialogue, often concerned with economic motivations, and such democratic conversations would be difficult to come by. Bowles and Ginitis (1976) suggest these types of conversations feed our ideology of a democratic society. For this reason, scientific literacy for the *individual* is of critical importance and individuals should strive to self-educate and identify reasoning that support informed decisions (Sadler, 2004; Sadler & Zeidler, 2005; Zeidler & Keefer, 2003). What Roth and Lee neglect to acknowledge are the instances in which individuals are required to make a decision on their own or with limited exposure to expertise. Such examples include parents who must make a decision regarding their unborn child diagnosed with a genetic disorder, or members of a jury who must consider DNA evidence in a murder trial. These individuals are generally sequestered from established communities of practice that might inform their actions. Instead their own beliefs and prior knowledge weigh heavily on their decisions. In such instances, individuals' scientific literacy is important for informed decision making.

One area of research that demonstrates the lack of connection between scientific literacy as a collective praxis versus an individual pursuit is the rights and responsibilities of citizens, researchers, and policymakers in the new genetics era (Kerr, 2003). The new genetics era is defined as the post-eugenics movement that was spurred by the human genome project and the hunt for genes that contribute to genetics disorders. The goals of this era is to determine the function of specific genes in genetic disorders and attempt to take corrective action or at least generate tests that can determine if patients are affected. Such tests can also be used after birth to determine the probability of late-onset diseases

(e.g., Huntington's, Alzheimer's, Parkinson's disease, etc.). Kerr (2003) emphasizes that the eugenics movement is long gone, but to assume that autonomy, participation, and contingency might not be affected anymore would also be shortsighted.

Studies in public understanding of genetics tend to overlook professional discourse of responsibility (e.g., how genetic counselors advise and guide patients and policy makers). In the new genetics era, Kerr (2003) finds that an emphasis is placed on patients' rights but the use of those rights by patients, is largely guided by experts - genetic counselors. Patients have an unspoken responsibility to self-educate, but are found to have little impact on how professionals and policy makers respond to the new genetics era. In general, the professionals who preside over patient organizations largely control patients' influence on genetic research and services. Policy makers have moved away from the 'deficit model' of public understanding of genetics and instead favor educational programs that help promote public engagement. However, the public is still dependent upon professionals to mediate these educational opportunities, and with the influence of the media (many media sources use scare tactics to sway public opinion about genetics research), this interaction becomes challenging. Kerr (2003) calls for members of the public to educate themselves about genetics and policies relevant to genetics. Policies are dependent upon technical expertise, so the public is limited in their ability to contribute. However, the responsibility of self-education and self-surveillance remain. Kerr (2003) acknowledges the view of scientific literacy as shared (no one can be considered an expert in all scientific topics), so measuring scientific literacy across a community with varying expertise is appealing in many instances. However, this definition is limiting when individuals with little knowledge of science or exposure to

expert interpretations are required to make high stakes decisions about issues relevant to their daily lives. In these cases, individuals' scientific literacy takes precedence over the community as a whole.

1.1.3 Exploring vision II.

To state that one approach for defining scientific literacy is better than another is short sighted - each has its merits. However, this dissertation focuses on Robert's (2007) Vision II as a means for exploring what scientific literacy - more specifically, genetics literacy - looks like in practice and what *individuals* need to know in order to reason about issues they may encounter throughout their lives. As noted by DeBoer (2000), scientific literacy is difficult to define and even harder to measure. It is unlikely that students graduating high school can be considered scientifically literate, "although what they learn in school will certainly affect their attitudes about science and their desire to continue to learn in the future" (p. 598). In fact, assessments such as PISA demonstrate this to be the case - 15 year old students in the United States scored lower than average marks in 2006 and average marks in 2009 on the scientific literacy component of the PISA assessment relative students in other industrialized countries (National Center for Education Statistics [NCES], 2010). DeBoer (2000) continues by acknowledging that classroom science at least introduces students to issues present in modern society, and it is with this hope that DeBoer envisions the development of scientific literacy across individuals' lifetime.

Understanding how individuals reason about authentic scientific dilemmas is essential to understanding the relationship between science and society. Currently, there are several strands of research examining this relationship, in which the majority consider

public opinion about science such as concerns raised by the commoditization of science (Baskaran & Boden, 2004), public trust in scientific authorities (Bauer, 2009; Kerr, Cunningham-Burley, & Amos, 1998), and government regulation of scientific technologies for use by the public (Kerr, 2003). However, from an empirical standpoint, we do not have a robust understanding of what scientific knowledge the public actually requires to reason about socio-scientific issues, and which issues they frequently encounter in their everyday lives (Feinstein, 2011).

We know that knowledge of concepts alone does not suffice - individuals need to be able to use their knowledge to formulate arguments, justifications, and make informed decisions (Erduran, Obsborne, & Simon, 2004; Sadler & Donnelly, 2006; Zeidler, Sadler, Simmons, & Howes, 2005). Moreover, the underlying assumption of schooling, that knowledge of core concepts generalizes to a variety of issues and that individuals can reason equally well about diverse issues (when the underlying scientific principles are the same) is proving to be problematic (Bransford & Schwartz, 1999). Thus, a finer grained analysis of how individuals use science knowledge to reason about issues comprised of authentic situational features.

1.1.4 A case for genetics literacy.

Science continues to advance our ways of understanding and acting in the world at a startling rate. Scientific enterprises, especially those focused on genetic research, advance at a startling rate and encompass many topics including stem cell research, cloning, gene therapy, and genetically modified organisms, among others. Along with these advancements comes the responsibility of researchers, policy makers and the public to act according to moral and ethical standards when invoking the use of such

technology. For example, genetic screening for diseases is useful for early detection and treatment. However, public concern exists that results of such screening may be used by health insurance companies or employers to perpetrate genetic discrimination (Billings et al., 1992; Feldman, 2012). So much so that the United States Congress passed the Genetic Information Nondiscrimination Act in 2008 to protect Americans from such outcomes.

The public's understandings of the societal benefits and repercussions of these technologies are becoming increasingly important for both personal and civic engagement. This is especially the case in the current era of direct-to-consumer genetic technologies and tests that were previously only accessible through trained professionals. However, studies show that public understanding of genetics is limited, raising questions about the public's ability to provide informed consent to their use (Condit, 2010; Miller, 2004; National Research Council (NRC), 2001; National Science Board (NSB), 2000). While the teaching of genetics begins at the middle school level (NRC, 1996); many students who leave compulsory schooling lack basic skills in all areas of genetics (Mills Shaw, Van Horne, Zhang, & Boughman, 2008) and exhibit alternative conceptions about many of the core ideas in the domain (Marbach-Ad & Stavy, 2000; Mills Shaw et al., 2008). Such conceptions may limit students' ability to reason about socio-scientific issues (Sadler, Chambers, & Zeidler, 2004), such as issues concerning genetic engineering, cloning, or stem cell research.

Despite including similar underlying genetic principles, studies show that students often reason very differently across issues with varying situational features (Bransford & Schwartz, 1999; Hammer, 1996; Schwartz, Bransford, & Sears, 2005). Sadler and Fowler

(2006) suggest that the robustness of students' genetic content knowledge may limit transfer of such knowledge across a variety of issues. The problem of what knowledge is needed to reason about socio-scientific issues is particularly acute in genetics since new issues crop up around major technological breakthroughs, such as the sequencing of the human genome in 2003. This event launched genetic research into the new direction of developing screens for previously undiagnosed genetic disorders. Such advancements raise questions about the public's ability to participate knowledgeably in socio-scientific debates, and to provide informed consent for a variety of novel procedures. What we do not yet know is what content knowledge individuals require as they consider these kinds of issues. Content knowledge is often considered the main component of genetic literacy. However, it must also be coupled with individuals' ability to apply their knowledge across many distinct issues and generate well-supported arguments to support civic engagement in discussions as well as personal decision-making.

Although genetics literacy is not well defined in the research literature, three themes commonly arise that serve to define genetics literacy in this dissertation. They are: (a) content knowledge of genetics (Duncan & Reiser, 2007; Bowling et al. 2008; Marbach-Ad, 2001; Venville, Gribble, and Donovan, 2005), (b) the use of genetic content knowledge to develop and evaluate arguments (Bates, 2005; Jiménez-Aleixandre, Bugallo Rodriguez & Duschl, 2000; Sadler & Donnelly, 2006; Zohar & Nemet, 2002) and one component not previously considered as part of genetics literacy: (c) individuals' ability to apply both content knowledge and argumentation skills across different issues comprised of varying situational features (Ceci & Ruiz, 1993; Chi, Feltovich, & Glaser, 1981; Nehm & Ha, 2011; Heredia et al., 2012). While individuals' ability to apply their

knowledge and skills across issues is not unique to genetics there is little research about the role of situational features that influence reasoning in genetics education.

Very few studies explore the relationship between content knowledge use and argumentation quality, particularly about authentic genetic dilemmas (Sadler & Fowler, 2006; Zohar & Nemet, 2002). We also know very little about how different features of issues constrain or facilitate individuals' reasoning abilities (e.g., Berland & McNeill, 2010; Nehm & Ha, 2011). Understanding the dynamic between these components is important for determining how individuals with varying levels of genetic knowledge reason about authentic problems may encounter throughout their lives.

1.1.5 Overview of the three studies.

The following three studies take different approaches to address the question: *How do individuals use their genetic content knowledge to reason about authentic issues they may encounter in their daily lives?* This question serves to examine individuals' genetics literacy as they encounter authentic genetics issues. Findings from these studies contribute to the literature by demonstrating how content knowledge, reasoning, and situational features of issues contribute to genetics literacy.

In the first study (Chapter 2), I interviewed early career and late career undergraduate science majors (n=20) and presented them with two reasoning tasks (one about plant genetics and the other about human genetics). The study used mixed methods to determine what kinds of genetics content knowledge participants used to generate and support arguments about each task. Findings demonstrated significant differences in argumentation ability - particularly for the early career students - across both tasks. These students preformed better on the human task than on the plant task. Late career

undergraduate students performed equally well on both tasks. This finding suggests that differences in reasoning ability may be dependent on content knowledge, but situational features of the task can also influence how individuals generate arguments.

In the first study, I examined two particular issues. However, it was conceivable that many other issues - and features of those issues - exist that might also influence reasoning. In my second study (Chapter 3), I took an empirical approach to explore the kinds of situational features that arise in news articles. By conducting an inductive content analysis of the articles, I was able to determine which features were most prevalent and what kinds of genetics content knowledge I anticipate as necessary for understanding issues comprised of those features. Findings from this study revealed that most genetics news articles discuss an anthropocentric story describing the use of genetic technologies at the biochemical and organismal levels (i.e., description of molecular entities and how they relate to physical traits) to identify, alleviate, or cure a genetic disorder of a physiological nature. Several themes of knowledge along with specific levels of sophistication were identified as necessary for understanding issues comprised of these situational features. This finer grained approach to analyzing knowledge requirements relative to media presentations of genetics, led to the final study that tested my conjectures about how individuals reason about such issues.

The final study (Chapter 4) sought to explore how individuals with varying levels of genetics content knowledge and argumentation ability reasoned about an issue comprised of the most prevalent situational features identified in the second study. This study analyzed participants' reasoning strategies as they considered the issue presented in the interview task. Four groups of individuals (undergraduate science majors, graduate

students in the sciences, graduate students in philosophy, and certified genetic counselors; n = 60) participated in the study. Content knowledge and reasoning assessments and a semi-structured interview were used to capture content knowledge application and reasoning ability. Findings from this study demonstrated that participants generated two distinct models of reasoning. These models were either limited or afforded by their use of genetics content knowledge and reasoning ability, particularly in terms of their use of sophisticated knowledge representations. This reflected my conjectures about knowledge requirements identified in my second study and reinforced findings concerning content knowledge sophistication from my first study.

Findings from all three studies have the potential to guide decisions about what to teach in k-12 science classrooms. By identifying what components most influence the development of scientific literacy, educational researchers and practitioners can map these theoretical models onto their analysis of student learning and achievement. Although this dissertation focuses primarily on understanding of genetics issues, the broader implications of this work are applicable to fields outside of genetics. This is especially the case in terms of methodological approaches for studying the interactions of content, situational features of issues, and reasoning in a variety of scientific domains.

Chapter 2:

Exploring content knowledge use and argumentation by undergraduate students across two distinct genetics dilemmas

Abstract

Genetic literacy is becoming increasingly important as advancements in our application of genetic technologies such as stem cell research, cloning, and genetic screening become more prevalent. However, many high school graduates lack the genetic knowledge necessary to participate in public debates over emerging genetic technologies. Very few studies examine the relationship between argument construction and genetic content knowledge when reasoning about authentic genetic dilemmas characterized by distinct situational features. We present our findings from a comparative interview study between novice (freshman/sophomore) undergraduate students majoring in biological sciences and advanced (junior/senior) undergraduate students majoring in genetics. We conducted semi-structured interviews composed of two distinct, authentic reasoning tasks: one concerning plants and the other concerning human genetics. We assessed student dialogue for genetic content knowledge and quality of argument construction. Overall, we found that advanced students more frequently applied their content knowledge of genetics, within each group reasoning strategies differed across tasks, and reasoning about genetic mechanisms was difficult for both groups. This work provides insights as to the conceptual obstacles and leverages involved in complex reasoning in the domain of genetics.

2.1 Introduction

Science continues to advance our ways of understanding and acting in the world at a startling rate. Research in genetics is a clear example with many developments such as stem cell research, cloning, gene therapy, and genetically modified organisms, among others. Along with these advancements comes the responsibility of researchers, policy makers and the public to act according to moral and ethical standards when invoking the use of such technology. The public's understandings of the societal benefits and repercussions of these genetic technologies is becoming increasingly important for both personal and civic engagement, much of which relies on understanding scientific ideas in the domain (Ryder, 2001). Genetic counseling, genographic research, and gene therapy are among a few examples of how genetic technology is used by scientists and non-scientists. However, the public's understanding of genetics is limited, raising questions about individuals' abilities to make informed decisions concerning the use of genetic technologies (Miller, 2004; National Research Council (NRC), 2001; National Science Board (NSB), 2000).

While the teaching of genetics begins at the middle school level (NRC, 1996); many students who leave compulsory schooling lack basic skills in all areas of genetics (Mills Shaw, Van Horne, Zhang, & Boughman, 2008) and exhibit alternative conceptions about many of the core ideas in the domain (Duncan & Reiser, 2007; Lewis & Kattmann, 2004; Venville & Treagust, 1998; Marbach-Ad & Stavy, 2000; Mills Shaw et al., 2008). Such conceptions limit individuals' abilities to reason about socio-scientific issues (Sadler & Zeidler, 2005). Socio-scientific issues "represent controversial social issues with conceptual, procedural, or technological ties to science" (Sadler & Donnelly, 2006,

p. 1463), such as issues about genetic engineering, cloning, or stem cell research. In order to participate in, benefit from, and provide informed consent for genetic procedures and technologies, individuals need to have better understandings of core genetics ideas and more robust argumentation skills (AAAS, 1989; NRC, 2007, 2011; NSB, 2000). In this case, core ideas refers to specific aspects of content knowledge in the domain of genetics that contribute to individuals understanding of the field such as notions of inheritance, meiosis, and molecular genetics. In this study, argumentation ability refers to individuals' skill at developing structurally sophisticated and relevant arguments and counter arguments about phenomena. Together, the application of domain-specific knowledge for the generation of arguments is referred to in this study as reasoning ability.

Very few studies thoroughly examine how individuals apply their domain-specific content knowledge while generating arguments and counter arguments about a phenomenon, particularly in domains that advance rapidly such as genetics (e.g., Sadler & Fowler, 2006; Sadler & Zeidler, 2005; Zohar & Nemet, 2002). Content knowledge is often considered the main component of literacy in any domain, and receives much of the attention in genetics education studies (e.g., Bowling et al., 2008; Dougherty, 2009; Lewis & Kattmann, 2004). However, to determine how individuals are likely to reason about genetics phenomena they encounter in daily life, an assessment of content knowledge must be coupled with individuals' ability to use their knowledge to make informed decisions (i.e., knowledge in use) (Roberts, 2007).

Two main branches of literature describe the relationship between content knowledge application and argument generation. Each stems from research on informal reasoning, but take different perspectives on the causal link between the two components.

Literature that comprises the first perspective suggests that what one knows (i.e., whether they have expertise or not) does not necessarily influence argumentation ability. For example, studies by Kuhn (1991, 1993), Perkins, Faraday, and Bushey (1991), Cerbin (1988), and Perkins (1985) suggest that having a broad knowledge base does not always lead to well developed argumentation skills and that argumentation requires training and practice. In general, these studies asked students to consider controversial or ill-defined topics they may encounter in their daily lives and develop positions supported by justifications. For example, Kuhn (1991) asked a variety of people (age groups and academic and professional backgrounds) to consider three topics: (a) what causes former prisoners to return to crime, (b) what causes children to fail school, and (c) what causes unemployment. Participants included high school students, non-college attending adults, experts in the field (e.g., experienced parole officers, experienced teachers, philosophy doctoral students). The topics presented to participants were chosen to represent domain general issues individuals are likely to encounter, but did not require the use of domain-specific knowledge for reasoning. Kuhn (1991) found that argumentation skills varied across participants, but were not determined by their content knowledge. Kuhn (1993) states, "Parole officers reasoned no better about the crime topic than they did about other topics, nor did teachers reason better about the school topic" (p. 92). The relationship between content knowledge and argumentation appears less obvious when individuals are asked to reason about issues that are domain general.

The second branch of literature that explores the relationship between knowledge application and argumentation suggests that increased knowledge of a particular domain supports argumentation ability in that domain. Studies such as those by Fleming (1986a,

1986b), Tytler, Duggan, and Gott (2001), Hogan (2002), Wu and Tsai (2007), Mason and Scirica (2006) and Sadler and Zeidler (2005) examine how students reason about issues tied to a particular science content domain. For example, Sadler and Zeidler (2005) asked undergraduate students - both science and nonscience majors - to reason about issues concerning genetic technologies such as gene therapy and cloning. They found that variations in content knowledge predicted differences in argumentation ability such that more sophisticated, domain-specific knowledge generally implicated more sophisticated argumentation (in terms of structure and soundness). Studies that include reasoning tasks that require highly specialized and domain-specific knowledge tend to demonstrate that more nuanced content knowledge leads to more robust argumentation. This conclusion makes intuitive sense since individuals with deeper content knowledge about a particular issue have a richer understanding of contributing factors and how factors integrate with one another to explain a phenomenon (Mason & Scirica, 2006; Sadler & Zeidler, 2005).

In general, these studies examined how individuals reason about domain-specific phenomena by examining what knowledge is applied and the sophistication of the argument generated for one or multiple reasoning tasks. Very few studies take a finer grained approach to examine if or why knowledge application and argument sophistication differs across reasoning tasks. For example, Mason and Scirica (2006) found that eighth grade students provided richer arguments (i.e., a greater number of rebuttals) for a reasoning task about transgenic food versus a task about global warming. The authors suggest that variations in prior knowledge about each topic may account for differences in argumentation skill. Prior knowledge in this case provides more factors from which to draw in support of claims and counter claims. Given that these two tasks

were born of very different domains - genetics and environmental science - it is plausible to assume that prior knowledge levels contributed to this difference. However, in cases where variation in reasoning ability exists despite similarity between tasks (i.e., same domain), other factors such as differences in the situational features of the task itself may play a greater role in differentiating reasoning ability.

In our own work, we found that middle school students' application of content knowledge to explain phenomena was more robust when presented with tasks about genetics issues in humans versus in plants or bacteria despite content knowledge requirements being the same across tasks (Freidenreich, Duncan, & Shea, 2011). We suspected that the situational features of these phenomena mattered in terms of how students apply what they know when generating arguments about an issue. In other words, individuals with greater diversity of situational knowledge - familiarity with a variety of issues within a domain - are more likely to demonstrate more robust reasoning ability than individuals with less situational knowledge. The question remains: What situational features influence reasoning ability about domain-specific phenomena?

In this study we take a finer grained approach to examine undergraduate students' application of content knowledge and their argumentation quality about two distinct, domain-specific issues in genetics. This work supports findings in the literature that a relationship exists between one's ability to apply content knowledge and the quality of argument generation. Our findings extend the research literature by demonstrating that this relationship is influenced by the situational features of the reasoning task, which has implications for science learning and teaching. Specifically we sought to address the

following research questions as we interviewed undergraduate students with different levels of genetic knowledge:

1. What aspects of genetic knowledge are used to reason across different authentic genetic issues?
2. How does argumentation quality differ across different authentic genetic issues?

2.2 Literature Review

There are currently several ways in which scientific literacy is defined, many of that include notions of knowledge in use (Ryder, 2001). Paul Hurd initially popularized the term scientific literacy in 1958 and later provided his definition as "a civic competency required for rational thinking about science in relation to personal, social, political, economic problems, and issues that one is likely to meet throughout life" (Hurd, 1998, p. 410). As the notion of scientific literacy developed, Roberts (2007) contributed two broad perspectives on its meaning, that he termed Vision I and Vision II. Vision I focuses on what individuals need to know or do in order to be considered scientifically literate (i.e., notions outlined by education reform initiatives, such as *Project 2061* (AAAS, 2001)), while Vision II focuses on what science literacy looks like in action (i.e., how scientific knowledge is used to reason about problems encountered in daily life). These descriptions of scientific literacy hold in common the need for scientific knowledge and use of such knowledge to reason about authentic scientific issues. Authenticity in this study is defined as actual or realistic phenomena that have relevance to individuals and may be encountered in daily life.

The Vision II perspective of scientific literacy (i.e., knowledge in use) embodies the focus of this study since we examine how undergraduate students apply knowledge of

genetics to generate arguments about authentic issues. Given the precise nature of the knowledge needed to reason about genetics phenomena, we use the term genetics literacy to further specify how we conceive of Vision II in this study. Literacy in the domain of genetics is not clearly defined in the research literature. However, three components are commonly discussed and therefore serve to define genetic literacy in this study. They are: (a) application of genetics content knowledge in terms of identifying relevant knowledge and using it to explain the underlying mechanisms of genetics phenomena (Duncan & Reiser, 2007; Bowling et al. 2008; Marbach-Ad, 2001; Venville, Gribble, and Donovan, 2005) and (b) the use of genetic content knowledge to develop, support, and evaluate arguments about genetics phenomena (Jiménez-Aleixandre, Bugallo Rodriguez & Duschl, 2000; Sadler & Donnelly, 2006; Zohar & Nemet, 2002).

We add to this definition by considering a third component: (c) the role of situational features of a reasoning task in terms of influencing individuals' genetic literacy. While situational features are not unique to genetics, there is little research about the role of such features in reasoning about genetics phenomena (Mason & Scirica, 2006). Situational features, more broadly construed, can influence reasoning in terms of both knowledge application and argument generation (Ceci & Ruiz, 1993; Chi, Feltovich, & Glaser, 1981; Schwartz, Bransford, & Sears, 2005). This is particularly evident in studies of knowledge transfer from one issue to another (e.g., Gick & Holyoak, 1980). We also consider the role of situational features as influential in supporting genetics explanations and knowledge application for argument construction. However, very few studies explore what situational features - particularly in genetics - generate differences in reasoning ability. The purpose of this study is to explore how situational features of

authentic issues affect differences in content knowledge application and argumentation across as undergraduate students reason about two distinct genetics phenomena. Understanding how such features influence reasoning is important for informing assessment and curricular design to promote engagement with science issues likely encountered in life. In this section we describe the background literature pertaining to situational features, knowledge application, and argumentation and how our study supports and extends research in these areas.

2.2.1 The Influence of Situational Features on Reasoning

In science education, notions of how individuals reason about an issue often consider how a phenomenon is framed in terms of the situational features that comprise and describe a phenomenon. For example, Nehm and Ha (2011) explored differences in knowledge elicitation patterns as a result of distinct situational features across evolutionary biology assessment items. They suggest that specific situational features play a significant role in how individuals reason about such problems. For example, they demonstrated in their study of item feature effects that undergraduate biology students were more likely to generate naïve biological explanations about trait loss versus trait gain scenarios that included the comparison of different situational features, such as within or between species comparisons, different taxa (e.g., plant and animal), and different traits (e.g., morphological, sensory, and behavioral).

There are likely multiple situational features that have the potential to influence reasoning about genetics phenomena. For example, individuals may reason differently about issues where a genetic mutation is the underlying mechanism that generates a physical trait in organisms. Genetic mutations are often viewed as harmful events that

lead to disease states, such as sickle cell anemia in humans (Kampourakis & Zogza, 2009). Therefore, it is likely that individuals may consider the molecular mechanism for a disease state to include genetic mutations. They may be less likely to understand that "normal features", such as freckles or attached ear lobes in humans, arise from genetic mutations as well. Conceptualizing mutations as detrimental, beneficial, or benign requires similar knowledge of genetics (e.g., molecular mechanisms) yet differences in whether the trait is caused by a disease state versus occurring as a normal function of the organism may influence reasoning strategies. A growing consensus supports the idea that situational features are a critical aspect of how individuals reason about socio-scientific issues and that instruction in science classrooms (K-16) is limited in supporting students reasoning about issues cast in a variety of authentic issues. This leaves students ill prepared to effectively engage with science in their daily lives (e.g., Jiménez-Aleixandre, Bugallo Rodríguez, & Duschl, 2000). It is still unclear whether specific features of issues drive decision-making or if together they can distract individuals from the underlying conceptual nature of various issues.

In this study, our use of situational features focused on the physical attributes that comprise a socio-scientific issue, such as type of organism, technological resources, and pathology. We developed two reasoning tasks, one about genetic engineering in plants and the other about a genetic disorder in humans - each required similar underlying knowledge of genetics. We chose to include plants and humans in our reasoning tasks since all of our undergraduate participants had completed coursework in genetics that discussed each type of organism. In addition, in our own work (Freidenreich, Duncan, & Shea, 2011) we found that middle school students had difficulty reasoning about genetics

phenomena in plants versus those described in humans, thus we were interested to see if reasoning differences across these two issues persisted in the undergraduate years. In other studies of undergraduate students' reasoning about evolutionary issues (e.g., natural selection), tasks that compared animals and plants demonstrated noticeable differences in students' reasoning (Heredia, Furtak, & Morrison, 2012; Nehm & Ha, 2011). Thus, we chose to feature animals (in this case, humans) and plants (specifically corn) in our work to elicit observable differences in participants' reasoning abilities. We expected that differences in situational features would elicit differences in knowledge application and argumentation quality, despite the need for similar content knowledge across both tasks.

2.2.2 Use of Content Knowledge

Research literature investigating what individuals - particularly undergraduate students - actually know about genetics and how this knowledge is used to generate and support arguments across various issues is limited (Duncan, 2007; Sadler & Fowler, 2006; Sadler & Zeidler, 2005). To investigate content knowledge and its application, we drew on the work of Stewart, Cartier, and Passmore (2005) who identified three major models of genetics knowledge that they argue comprise the knowledge component of genetics literacy; (a) the genetic (or inheritance) model, that describes the pattern of inheritance between parents and offspring, (b) the meiotic model that describes the passage of genes from parent to offspring through sperm and egg, and (c) the molecular model that describes how genes are translated into proteins that bring about physical traits. Stewart et al. (2005) suggest that genetic literacy entails understanding the models themselves as well as how they relate to one another. These three models of genetics speak specifically to what students should know about genetics, but leave out how this

knowledge is applied while considering genetics phenomena and what students find difficult to explain.

Research on genetics knowledge use suggests that students of all ages have greatest difficulty describing the mechanisms underlying and connecting each model (van Mil, Boerwinkel, & Waarlo, 2011). Marbach-Ad and Stavy (2000) suggest that mechanistic reasoning (describing the underlying casual mechanism of a phenomenon) is challenging for individuals for two reasons. First, mechanistic reasoning entails knowledge of the main organizational levels that support the phenomenon: macroscopic (organismal), microscopic (cellular), and molecular (biochemical) levels; and second, mechanistic reasoning is challenging because individuals require familiarity with biological components of genetic mechanisms (i.e., how genes relate to proteins, and how proteins bring about traits). Without knowledge about molecules, such as proteins and their central role in genetic mechanisms, individuals will struggle to productively reason about complex genetic phenomena (Duncan, 2007). Thus, molecular explanations often act as a gatekeeper for students' understanding of genetics phenomena.

Very few studies examine how students construct molecular explanations of genetic phenomena or what they find difficult to understand (Duncan, 2007; Duncan & Reiser, 2007). In this study, we asked undergraduate students with varying levels of genetics knowledge to provide an underlying molecular mechanism for genetics phenomena across the two reasoning tasks. The reasoning tasks were constructed so that knowledge required of molecular entities (e.g., genes and proteins) and their relationship to observable traits was similar across tasks. This provided us the opportunity to explore not only how students applied content knowledge to construct explanations, but also

examine how situational features or tasks influenced reasoning ability.

2.2.3 Generating and Supporting Arguments

In addition to genetics content knowledge application, we also explored the use of content knowledge for the generation and support of arguments about phenomena as an essential component of genetics literacy. In its simplest form an argument requires providing a claim supported with a logical series of justifications, such as warrants, backings, and evidence (Erduran et al., 2004; Toulmin, 1958). In this seminal work, *The Uses of Argument*, Toulmin described the individual components of argument and the relationship between each. A claim is one's declaration put forth for acceptance, which is then supported by data. Warrants provide links between data and claims, and backings strengthen warrants by providing further examples. High quality argumentation also includes the generation and evaluation of rebuttals, that indicate the conditions when a claim does not hold true (Erduran et al., 2004). The presence of a rebuttal constitutes a high quality argument "since a rebuttal and how it counters another's argument forces both participants to evaluate the validity and strength of that argument" (Erduran et al., 2004, p. 921). The ability to generate counterarguments is also indicative of high level argumentation skills since counterarguments essentially require students to consider views alternative to their own (Kuhn, 1991). These structural elements may seem straightforward, but developing sound arguments about a variety of issues is challenging (e.g., Chin & Osborne, 2010; Lewis & Leach, 2006; Sadler & Zeidler, 2005).

Many studies suggest a relationship may exist between content knowledge application and argument generation (Fleming, 1986a, 1986b; Tytler, Duggan, & Gott, 2001; Hogan, 2002; Wu & Tsai, 2007; Mason & Scirica, 2006; von Aufschnaiter,

Eduran, Osborne, & Simon, 2008). For example, Sadler and Zeidler (2005) present findings from a study that explored the presumed link between genetic content knowledge and argument generation. They sought to determine if undergraduate students' reasoning differed based on the extent of their genetic content knowledge. Sadler and Zeidler (2005) found that students with greater knowledge of genetics (based on assessment scores) provide higher quality arguments across genetic engineering issues measured by use of Toulmin's argument pattern. Thus, Sadler and Zeidler (2005) suggest that genetic content knowledge is a significant contributor to argumentation quality about socio-scientific issues. These finding are supported by Lewis and Leach (2006) who asked high school students to engage in discussion about applications of gene technology. In this case the authors found that relevance of the issue for the individual was an indicator of reasoning ability. Lewis and Leach (2006) state that "the ability to engage in reasoned discussion of social issues arising from the application of science is, to a large extent, determined by the ability to identify key issues of relevance" (p. 1282). Identification of key issues in this case is contingent upon the individual's understanding of the situational features that define the issue itself. Where these studies fall short is in the explanation of situationally-based reasoning differences and what situational features in particular are difficult for students to comprehend.

This study addresses the nature of situational features' influence on knowledge application and argument generation by applying a framework developed by Sadler and Donnelly (2006) that proposes a relationship between the two components of genetic literacy (described in the next section). We extend Sadler and Donnelly's theoretical

model by determining how the features of our reasoning tasks test the assumptions of their model.

2.3 Theoretical Framework

Sadler and Donnelly's (2006) model, the Threshold Model of Content Knowledge Transfer, was developed to explain the relationship between what students know about genetics and how this influenced the quality of their arguments about authentic genetic dilemmas (Sadler & Fowler, 2006; Sadler & Zeidler, 2005). It is important to note that by argumentation quality Sadler and his colleagues refer to the structural complexity of arguments determined by the types of justifications and number of justifications used to support claims. Sadler and Donnelly (2006) proposed that "incremental increases in content knowledge do not translate into similarly incremental increases in argumentation quality, but there are certain knowledge thresholds that confer noticeable increases in argumentation quality" (p. 1481). Thus, their model posits a nonlinear relationship between genetic content knowledge and argumentation quality.

Using an interview protocol comprised of several reasoning tasks about genetic engineering, Sadler and Donnelly (2006) explored how high school students, undergraduate science majors, and undergraduate non-science majors used their knowledge of genetics to develop and support arguments. They found that content knowledge could be divided into thresholds so that as students' knowledge surpassed a threshold, their quality of argumentation increased. These thresholds are described in four thresholds with the first threshold indicating little or no knowledge of genetics, the second threshold indicating "rules of the game knowledge" meaning the basic knowledge required to reason within the domain, the third threshold indicating "advanced

knowledge" meaning the knowledge obtained through disciplinary study, and the fourth threshold indicating professional or expert knowledge of genetics.

Findings from Sadler and Donnelly's (2006) work suggest that development of content knowledge and argumentation skills is connected. However, it is unclear how situational features of issues influence the connection between content knowledge application and argumentation or whether specific features of issues influence individuals ability to use these components. Despite understanding abstract principles of genetics, students likely have difficulty applying those ideas across situationally different reasoning tasks (Sadler & Fowler, 2006). It is likely that if individuals' knowledge is highly specific, they will have difficulty using their knowledge in support of arguments within ill-structured or unfamiliar issues (Heredia et al., 2012; Nehm & Ha, 2011). In this study we used the Threshold Model of Content Knowledge Transfer as a basis for exploring how situational features of issues influence the relationship between content knowledge application and argumentation.

2.4 Methods

2.4.1 Study Context

We used convenience sampling (Patton, 1990) in undergraduate science survey courses to recruit twenty undergraduate students from a large state university in the Northeastern United States. We recruited eleven participants who were freshmen/sophomores (that we call novice students) intending to major in a science field who had completed General Biology and no other courses in which genetics was taught, and nine participants who were junior/senior genetics majors (that we call advanced students) and had completed the majority of their genetics coursework including genetics

content courses, genetics laboratory courses, seminars on current issues in genetic research, and genetics elective courses such as cancer genetics or evolutionary genetics. These groups were chosen in order to determine if there exist observable differences in the way students with different levels of content knowledge reason about authentic genetic dilemmas. None of the participants received formal training in argumentation (e.g., courses that included direct instruction on formal and informal reasoning), so we expected that participants' argumentation skills were relatively similar to one another. However, we did not test this hypothesis at the time of recruitment. It is possible that participants' differed in terms of argumentation skills based on academic ability level as seen in other studies of informal reasoning with students at various grade levels, ability levels, and understanding of scientific practices (Ford, 2008; Means & Voss, 1996). However, participants in this study had similar GPA's in each group indicating similar academic abilities and completed similar coursework in each group. The groups were comparable in terms of race and gender. Although the novice students' grade point averages (GPA's) were lower than those of the advanced students, we suspect this is a product of time spent in school. Demographic data for the participants is provided in Table 2.1.

Table 2.1.
Demographic information for the 20 participants

Novice Students[a]	**Intended[a] / Declared[b] Major**	**GPA**	**Degree Completion**	**Gender**	**Self- Described Ethnicity**
	Biomedical Engineering	2.6	Sophomore	Male	Indian / White
	Dietetics	3.0	Sophomore	Female	White
	Public Health	3.0	Sophomore	Male	Asian
	Sciences – undecided	2.7	Sophomore	Female	Southeast Asian
	Exercise Science	2.9	Sophomore	Male	Latin Caribbean
	Exercise Science	3.0	Sophomore	Female	White
	Sciences – undecided	3.0	Sophomore	Female	Euro- American
	Cell Biology	3.0	Sophomore	Female	Pakistani
	Biology	2.7	Freshman	Female	Indian
	Environmental Science	3.3	Sophomore	Male	White
	Sciences – undecided	3.2	Sophomore	Female	Indian
Advanced Students[b]	Genetics	3.5	Senior	Female	Indian
	Genetics	3.6	Senior	Female	Hispanic
	Genetics	3.0	Senior	Female	Hispanic
	Genetics	3.7	Senior	Female	White
	Genetics	3.4	Junior	Female	Asian
	Genetics	3.8	Junior	Female	Chinese
	Genetics	3.3	Junior	Male	White
	Genetics	3.5	Senior	Male	White
	Genetics	3.2	Senior	Female	East-European

2.4.2 Data Collection

We conducted individual interviews with all participants. The interview was semi-structured allowing for follow up questions on ideas discussed by participants (Brenner, 2006). More specifically, the differences in genetics knowledge were inferred from participants' ability to apply information learned in coursework and their ability to reason using this knowledge in the genetics task described. All interviews were audio-recorded and transcribed within four weeks after the completion of each interview.

To determine if situational features of tasks limited students' reasoning abilities, we designed two tasks based on similar underlying genetic principles (i.e., the three models of genetics) but with markedly different features (i.e., plant versus human

genetics). In the first interview task, we presented students with a newspaper article adapted from a true case (Margoshess, 1999) that depicted a court case where a small-scale farmer was sued for patent infringement by a large crop company after his fields were found to contain genetically modified corn. This task was designed to contain information that would be applicable to students who had only completed General Biology, but also to students taking advanced level genetics courses. The students were asked to read the article, discuss their opinions with the interviewer, and were then led through a discussion of the genetically related background information. This discussion was designed to elicit students' background knowledge of the mechanism underlying the genetic phenomena in the task. For example, students were asked to describe the process of genetic modification of foods such as corn, how corn can be genetically engineered to manifest a particular trait such as herbicide resistance, and how unmodified corn could acquire "engineered genes" when grown near fields of modified corn. Ultimately students were asked to consider their responses to such questions when determining the guilt or innocence of the farmer depicted in the court case.

In the second interview task, students were presented with several photographs of individuals with severities of albinism (a pigmentation disorder that can effect skin, hair, and irises) and asked to reason about the biological mechanism of the disorder and how such severities develop. For example, students were asked to describe how albinism is caused and what is occurring in someone's body (at the level of the genes) that has albinism. Students were also asked to describe the genetic differences between the most severe form of albinism versus a milder version. For example, students were asked to consider why an individual with mild albinism only had hair that appeared lighter than

normal versus an individual with severe albinism whose skin, hair, and irises were all lighter than normal. One photograph included a fictional story about a paternity case in which two normal-looking parents disagreed about the paternity of their three albino children. The students were asked to reason about the genetic probability supporting the outcome of the case. Topics discussed in both tasks were familiar to the students and required knowledge of the three models of genetics. These tasks also provided a rich venue for argumentation construction and reasoning about claims. Additional materials including readings and sample questions from the interview protocol are available as supplementary material accompanying the online article.

2.4.3 Data Analysis

To answer our first research question concerning the difference in how genetic content knowledge was used by students in the two groups, we conducted a content analysis of the interview transcripts for both tasks to determine students' use of knowledge of the three conceptual models of genetics (Stewart, Cartier, Passmore, 2005). The three models include: (a) the inheritance model, that describes the patterns of inheritance between our genes and our traits, (b) the meiotic model, that describes how the genetic material is physically passed down from parent to offspring through egg and sperm, and (c) the molecular model, that explains how the genetic information is translated into physical entities- proteins- that bring about the observable traits. Data analysis began by reading each task of the interview and identifying patterns across responses that mapped onto the three models of genetics (Coffey & Atkinson, 1996). Instances of correct and incorrect application of knowledge for each model were noted. Correct usage of knowledge was defined by the canonical accuracy of the information

provided by the students in their responses to interview questions. During the sections of the interview that focused on students' content knowledge, we counted the frequency with which students referred to each of the three models for both tasks. Two independent coders analyzed 50% of the data. The inter-rater reliability was >90% for both tasks.

The analysis of knowledge use across the three models shed light on how students applied their understandings of genetics in these tasks; however from this analysis we did not get a good sense of the depth or complexity of their understanding. In order to capture such complexity we looked at their mechanistic reasoning, meaning their ability to provide a causal link between distinct phenomena such as genotype (genetic coding of DNA) and phenotype (observable traits). We specifically focused on the instances of dialogue referring to the molecular model in order to determine the specificity with which students' use of content knowledge differed. We chose to focus on the molecular model since our initial readings of the transcripts did not suggest significant differences in understandings across the two groups for either the inheritance or meiotic models.

In prior work, Duncan, Rogat, & Yarden (2009) developed a hypothetical learning progression in genetics for middle and high school grades. The learning progression identified eight big ideas in genetics that map onto the three conceptual models of genetics and the relationships between models. The learning progression also specified three levels of sophistication for each of the big ideas as students progress through school. To explore students' understanding of the molecular model in this study, we applied a coding scheme that captured the complexity of students' reasoning about the molecular model from the learning progression (Table 2.2). Using codes from the learning progression was productive in this study since the learning progression is the

most detailed account of genetics knowledge requirements currently in the field of genetics education and our reasoning task emphasized knowledge of genes and proteins that corresponds with the molecular model of genetics. These codes also mapped onto the thresholds presented in Sadler and Donnelly's (2006) Threshold Model, as shown in Table 2.2.

Table 2.2.
Coding scheme with interview excerpts for sophistication of knowledge

<table>
<tr><th>Threshold</th><th>Level</th><th>Description</th><th>Interview Excerpts</th></tr>
<tr><td rowspan="2">Little / No knowledge</td><td>0</td><td>No understanding of the function of genes or have no knowledge of genes.</td><td rowspan="2">Int: Do you think that genes have anything to do with this [generating herbicide resistant plants], or is that just something completely different?

Ethan: Genes might have something to do with it, if it's happening naturally. But then if you're altering it, then it's more like human work.

Int: And what do genes have to do with it in the natural way?

Ethan: Genes might…I don't know how that…</td></tr>
<tr><td>1</td><td>Genes are non-informational in nature. They are passive particles associated with traits.</td></tr>
<tr><td rowspan="2">Rules of the game knowledge</td><td>2</td><td>Genes are non-informational in nature. They are active particles associated with traits. Genes "determine" traits.</td><td rowspan="2">Int: So is there a relationship between genes and enzymes or are they completely separate things?

Purnima: Um… no I guess they can't be completely separate because um the genes that are carried to the next generation have to tell the enzymes like how to work…

Int: Can you describe to me what you think genes are?

Purnima: Genes are like your DNA that carry your characteristics. They give you your physical looks and stuff but they also like… carry like information about almost like how your body works, not just the physical characteristics but the functional parts.</td></tr>
<tr><td>3</td><td>Genes are active instructions that "tell" proteins, the cell, or the body to carry out specific functions.</td></tr>
</table>

Advanced knowledge	4	Genes have information about biological entities and function at multiple organization levels. Genes are "expressed", but there is no sense of what may result from such expression.	*Int: So is there a relationship between genes and enzymes?* Greg: There is a relationship between them. *(Hesitates)* I can't quite explain it very thoroughly but I'm guessing probably certain genes they code for certain things to be created. Such as, any type of gene maybe for my eye color you know probably that gene codes for something that is going to somehow work with an enzyme that makes the color of my eye.
Expert knowledge	5	Genes are instructions for molecules (many of which are proteins) that carry out functions within the organism. A change in a gene might result in the change to a protein's structure and function.	*Int: Do genes have anything to do with being albino?* Sonia: Yeah, genes do code for melanin production. Maybe he is albino because of low transcription of the melanin gene. *Int: Why would that happen?* Sonia: Perhaps due to some enzymes that's involved in the transcription such as polymerase or some other type of polymerase that transcribes the genome that produces melanin. Perhaps a defect in the protein structure or the binding site, it cannot recognize, or perhaps in the genome there is a problem with the response element that something interacting with the protein might not bind properly and thus cause albinism.
	6	The genetic code is transcribed and translated into a sequence of amino acids that makes up the protein. Almost all organisms use the same genetic code. Students may include how transcription and translation take place (i.e., mRNA, ribosomes, etc.)	

Little or no knowledge of genetics is essentially where individuals start out that have no formal training in genetics. They have difficulty making sense of genetics issues because they do not have any knowledge of genetic entities or mechanisms. Likewise, levels 0 and 1 in our coding scheme suggest this level of understanding for participants. For example, Ethan - a novice student, suggests that genes may have something with generating herbicide resistance in plants, but only if the mutation causing the resistance is

naturally occurring versus engineered (Table 2.2). In this case Ethan believes that if a plant is engineered by scientists to resist herbicides, genes are not involved in the process. This notion is not uncommon across students, but is inaccurate since scientists directly manipulate specific genes in order to confer resistance in plants.

Rules of the game knowledge is an analogy used by Perkins and Salomon (1989) and Sadler and Fowler (2006) that compares attempting to play chess without knowing the rules to generating arguments about socio-scientific issues without understanding the basic content knowledge that supports the issue. In our coding scheme, levels 2 and 3 correspond with this type of knowledge because at these levels individuals have a basic understanding of genetics terminology and how genetics entities actually work (e.g., that genes determine traits or that genes can tell molecular entities in the body to carry out some function). At this level individuals grasp that genetics phenomena can be described at multiple levels of organization: organismal, cellular, and biochemical. However, they are unlikely to describe the specific underlying mechanisms that contribute to genotypic and phenotypic differences. For example, Purnima - a novice student, describes genes as functional and deterministic of traits. She is does not provide a mechanism for how trait determination occurs other than stating genes "give you your physical looks". This notion of genes is not entirely incorrect. Genes are informational in nature and lead to the production of physical entities - proteins- that generate traits. Purnima's statement lacks clarity in terms of other players involved in trait determination and mechanism, but she demonstrates more sophisticated knowledge than Ethan since she can provide a functional definition for genes affording her rules of the game knowledge.

Advanced knowledge is defined by Sadler and Fowler (2006) as "understanding commensurate with the experiences of college students majoring in a discipline" (p. 990). They describe this knowledge as more detailed than what would be expected of high school students. From our own work, we find that "advanced knowledge" can be further parsed into more nuanced levels. We find that a threshold exists between individuals' ability or inability to describe a mechanism for a genetic phenomenon. Other researchers in genetics education indicate that students' ability to generate coherent and relevant mechanisms is difficult for students to do since it requires knowledge of multiple organizational levels and connections between conceptual models in genetics (Duncan, Rogat, & Yarden, 2009; Marbach-Ad & Stavy, 2000; Stewart, Cartier, & Passmore, 2005; van Mil, Boerwinkel, & Waarlo, 2011). Instead of lumping undergraduate students together in one category - advanced - we deviate from Sadler and Fowler's model to further parse advanced knowledge into advanced and expert knowledge.

For the purposes of our work, we consider advanced knowledge to be comprised of participants' ability to recognize organizational levels without the ability to generate an underlying mechanism. This is different from rules of the game knowledge in that at levels 2 and 3 individuals identify levels without the ability to connect them directly. For example, Greg - a novice student, demonstrates advanced knowledge of genes since he is able to identify genes as informational and leading to the production of "things" that brings about a trait. Greg knows that genes do not directly determine traits - he understands that "something" is produced by a gene that supports trait development. Although he is unable to identify what that thing might be. His explanation begins to resemble a mechanism as he describes the trait eye color as being determined by the

relationship between the "thing" genes generate and an enzyme. Again, Greg does not specify what enzyme or give an example of its function. His knowledge of genes is more advanced than Purnima's in this case.

We further explicate the threshold expert knowledge (alluded to in Sadler and Fowler's work, but not described in detail) as participants' ability to recognize organizational levels and generate an underlying mechanism that supports their explanation of the genetic phenomenon. These explanations often include notions of genetic mutation and gene expression processes such as transcription and translation to make proteins. For example, Sonia - an advanced student, describes several mechanisms that may confer albinism in humans. She suggests that the gene may not be expressed at normal levels ("low transcription") due to inefficiency of a specific enzyme (polymerase) that regulates the expression process. Sonia can also imagine a mutation in the enzyme regulating this process so that it can no longer function properly or a mutation in the gene that codes for pigmentation may inhibit interactions with proteins necessary for proper expression. All of these mechanisms are relevant to the issue and sophisticated in nature since they address the function of genes and enzymes relative to one another and how they work together to generate a trait. Sonia's response is more sophisticated than the other participants since she is able to explicate several mechanisms that may be responsible for the genetic phenomenon. For each task, we assigned students a level score indicating their highest level of mechanistic detail. Two independent raters coded all of the data for both tasks to reach consensus.

To answer our second research question concerning the difference in argumentation pattern between the two groups across tasks, we first identified each

coherent argument within each interview transcript. For each interview task, several individual arguments were generated by each participant. Toulmin's (1958) analysis of argumentation pattern explores the structural quality of arguments. Many researchers use this particular framework over others because of its widespread use in science education research, and its adaptability to a variety of data forms such as focus groups, student dyad dialog, and individual interviews (e.g., Jimenez-Aleixandre et al., 2000; Osborne, Erduran, & Simon, 2004; Zohar & Nemet, 2002). However, arguments are often difficult to analyze using Toulmin's argument pattern since distinguishing between what is considered data, backing, and warrant can be problematic (Erduran et al., 2004). This drew our attention to Sadler and Fowler's (2006) method of collapsing and grouping justifications that supports the exploration of argument quality while still maintaining levels of complexity. Table 2.3 describes the coding scheme we adapted from Sadler and Fowler's (2006) study to analyze individual arguments and provides an excerpt from the interviews as an example for each level. We used this particular coding scheme since we were interested in the structural quality of the arguments presented and this framework offered a means to circumvent the issue of identifying the difference between warrants, backings, data etc. Like Sadler and Fowler (2006), we coded students arguments based on the presence or absence of particular grounds.

Table 2.3.
Coding scheme for argumentation quality with example excerpts from interviews.

Level	Description	Interview Excerpt
1	Justification without grounds	*In response to plant task:* Yes, I think that could explain it [the farmer planted the modified corn himself].
2	Justification with simple grounds	*In response to human task:* I would just tell them that probably their parents, their fore-fathers, had this trait that has been carried on so far. And fortunately they didn't get it but in genetics you can't predict what will happen and unfortunately their children got both recessive traits and three of them got it and there's no other way, I mean that's how genetic works.
3	Justification with elaborated grounds	*In response to plant task:* I would stay with the researchers because they are just, based on genetics they know that there is gene flow. You have to have some basis in genetics to understand that case. You can't just simply ignore the fact that there's something with genes going on, it's not just you stole my corn and planted it here. Cause if it's right there's gene flow between GM [genetically modified] and natural corn, then I think it's a strong argument.
4	Justification with elaborated grounds and a counter-position	*In response to human task:* Very strongly towards the mother's side of the story, and not just for the random mutation theory of it. It's really complicated in this situation because the man doesn't remember his extended family. So he doesn't even know…maybe 300 years before hand maybe he did have some kind of albino family member. So maybe he's a carrier for it and autosomal recessive. And maybe she is a carrier for autosomal recessive. So just from that scenario alone you're going to get 25% of the progeny generated as completely recessive. And then she [the mother] could also be right too, which is probably a really low probability, impossibly low, where each of the children inherited the same mutation during pregnancy through some means,

Levels of argument sophistication were applied to each instance of coherent argument presented by the student, thus each student was assigned more than one level of argument quality. For each student, the level scores were averaged providing a final value representing their overall level of argumentation quality. To determine differences in argument quality across novice and advanced students for each task, we analyzed the averaged individual scores using the Mann-Whitney U Test. To determine differences in argument quality within groups for both tasks, we analyzed the averaged individual scores using the Related Samples Sign Test. We converted the z-scores from the Mann-Whitney *U*-tests and Related-Samples Sign tests into *r* to give an effect size based on Cohen's (1988) conventions of small, medium, or large effect, as suggested by Dytham, 2003.

2.5 Results

2.5.1 Analysis of Content Knowledge Use across Tasks

Our first research question sought to determine the differences in content knowledge use across the two groups of students and across tasks. In this analysis we specifically focused on instances of canonically correct knowledge usage. After tallying each instance of correct knowledge use for any of the three models at the end of both interview tasks, the scores were averaged for each group and overall for each task since the number of instances differed across participants (see Figure 2.1). Both tasks provided opportunities for students to discuss their ideas of the three models. However, both novice and advanced students applied knowledge of the molecular and inheritance models more frequently than that of the meiotic model in both interview tasks. This finding is also reflected in the data of other researchers who found that students generally

do not apply knowledge of meiosis when reasoning about genetic dilemmas (Lewis Wood-Robinson, 2000).

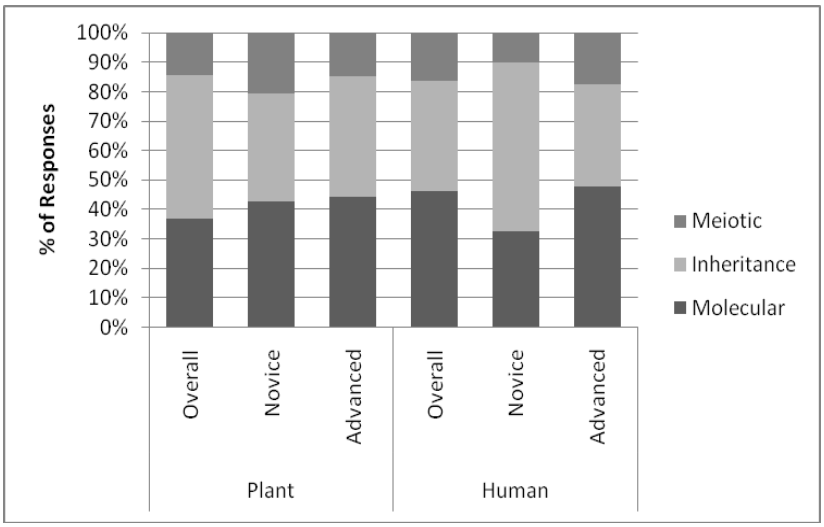


Figure 2.1. Students' use of the three models of genetics during each interview task.

Although these counts described the frequency with which students applied each model of genetics, it did not provide us a sense of the complexity of their ideas. In order to examine the levels of complexity of content knowledge use, we applied our coding scheme for mechanistic detail to students' ideas concerning the molecular model (Table 2.2). In terms of their mechanistic reasoning for the molecular model, the advanced students provided more complete and accurate mechanisms to explain the genetic phenomena for both tasks (Figure 2.2).

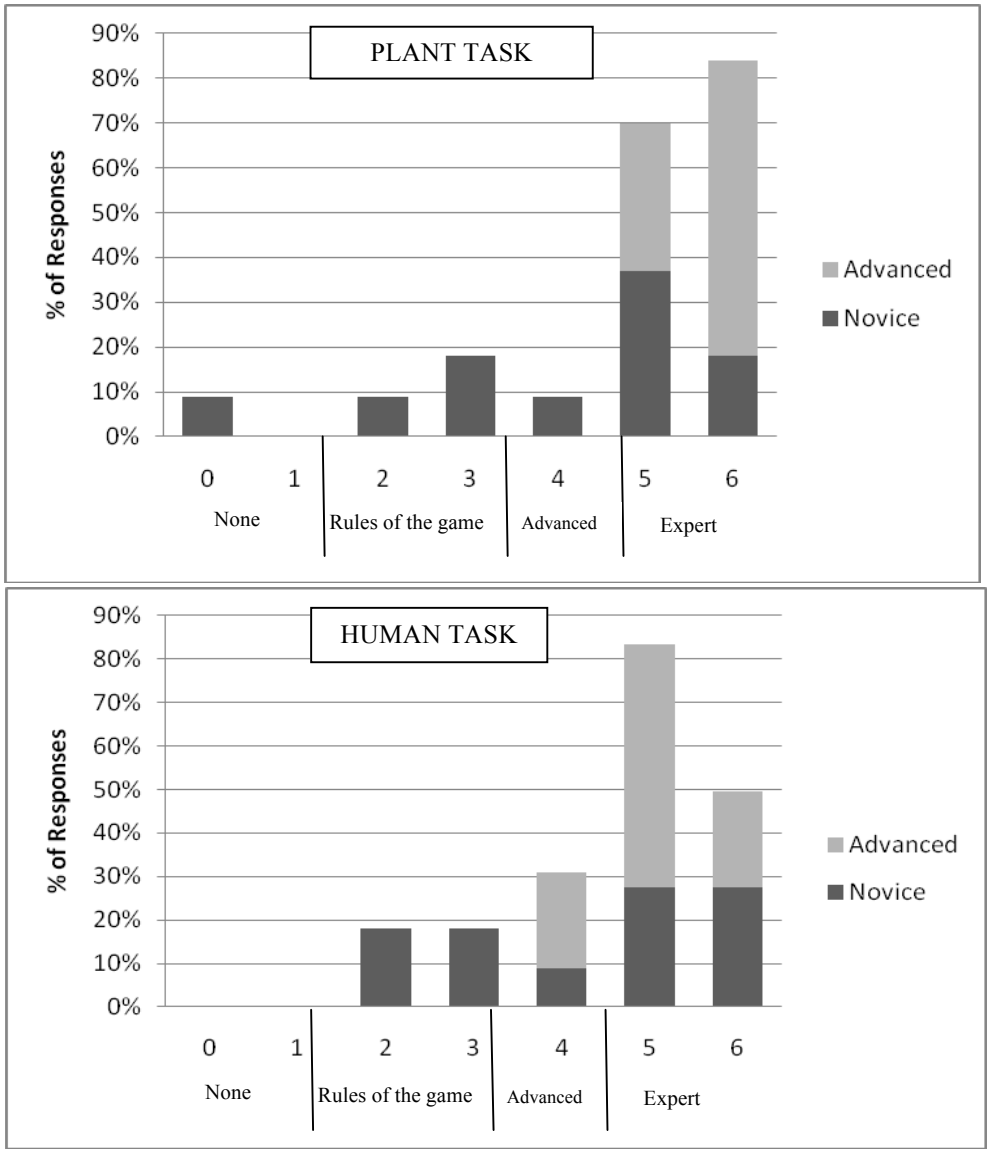


Figure 2.2. Students' level of sophistication of content knowledge with respect to the molecular model for each task.

All of the advanced students discussed the plant task at the expert threshold (levels 5 and 6). For example, Sonia describes the mechanism underlying the modification of corn to become resistant to herbicides:

Int Can you describe to me how the company made the herbicide resistant corn in the first place?

Sonia What I think they did was they would introduce some type of mutation in the genome to produce an altered structure of the protein so that they wouldn't have the binding site of the herbicide that actually binds to the protein enzyme to be exposed to the herbicide then kills off the plant. So this way they would sort of mask or somehow block that binding site and cause the herbicide not to bind to that binding site.

Int How would that binding site be masked or blocked in your mind?

Sonia Altered protein structure. Maybe changing their alpha beta helix position or maybe a different amino acid sequence that might be somehow coding for the structure to open the binding site or maybe a mutation in the coding region in the amino acid sequence might sort of block it.

Int How would they go about doing that?

Sonia One has to first sequence the protein structure, the protein sequence of amino acids and see how these protein structure combine and fold and somehow put itself all together to be a functional protein. And then doing a series of mutations in their amino acid sequence, one can know what effects the protein structure overall. So that's the only thing that comes into my mind.

Sonia immediately makes the assumption that a protein, in this case an enzyme, is contributing to the herbicide resistance of the corn. She suggests that the chemical herbicide can somehow attach to the enzyme via a "binding site" and if this binding site is altered the resulting plant becomes herbicide resistant. Sonia's response was coded as a level 5 (expert level threshold) for molecular mechanism because she made the connection between altering the plants genes or "genome" to affect a protein's structure and function - in this case altering the herbicide binding site. Understanding this connection between genes and proteins and that changes in genes may alter the function of corresponding proteins was common among the advanced students and indicative of

robust understanding of the molecular model. However, 22% fewer advanced students discussed the human task at the expert threshold.

Greater variation was observed among the novice students. For both tasks equal numbers of novice students (55%) reasoned at the expert threshold (levels 5 and 6). However, the remaining novice students (45%) provided less sophisticated understandings across tasks (levels 0 – 4). For example, LeAnn, a novice student, provides her explanation for the mechanism underlying albinism during the second interview task:

Int	Can you tell me what you think is going on inside his body to generate albinism?
LeAnn	Probably that the genes for the pigment in his skin, he got both the recessive ones from his parents. So he's got the lighter genes for skin color while his parents may have the darker genes for skin color.
Int	Now do proteins have anything to do with this?
LeAnn	No
Int	Nothing whatsoever. This is just genes doing something?
LeAnn	I think so.
Int	So the gene is recessive, and what is the outcome?
LeAnn	He has both the recessive genes for skin color so therefore he is much lighter than both his parents.

In this example, LeAnn describes the disorder as determined by genes (level 2, rules of the game knowledge). She is unable to draw a connection between genes and the function of proteins that would result in the disorder, however she does understand that genes are responsible for the observed phenomenon that are the basic "rules of the game" required

to reason about such an issue. Although the two interview tasks differ in terms of their situational features, understanding the relationship between genes, proteins, and traits exists across both tasks. This relationship, detailed in Sonia's explanation of the plant task, is not observed in LeAnn's explanation of the human task and is the leading difference between novice and advanced students in terms of molecular understanding.

2.5.2 Analysis of Argument Quality across Tasks

Our second research question sought to determine the differences in argumentation quality across the two groups of students across the two tasks. We were specifically interested in determining the structural complexity of students' arguments, meaning the strategies they used to support their claims. When discussing each interview task, students generated multiple arguments. Each argument within a task was scored based on its structural complexity. Table 2.4 illustrates the averaged scores for argumentation quality for both groups of students and across both interview tasks.

Table 2.4.
Mean and standard deviation for argument quality by group of students and task

	Plant Task		**Human Task**	
	Mean	Std Deviation	Mean	Std Deviation
Novice (n = 11)	2.46	0.48	3.00	0.40
Advanced (n = 9)	3.18	0.34	3.11	0.56

To determine if overall argumentation quality significantly differed between groups and across tasks, we used the Mann-Whitney *U*-Test and found that advanced students (Mean rank = 14.72, n = 9) performed significantly higher in average score for argumentation quality than novice students (Mean rank = 7.05, n = 11) for the plant task,

$U = 87.5$, $z = 2.906$, $p < 0.01$ two-tailed. The effect size ($r = 0.65$) can be considered large (Cohen, 1988). The Mann-Whitney *U*-Test also showed that there was no significant difference in average score for argumentation quality between novice students and advanced students for the human task.

To determine if the differences in argumentation quality within groups across both tasks was significant, we used the Related-Samples Sign Test and found that novice students had significantly higher average scores for argumentation quality on the human task compared to the plant task, $n = 11$, $T = 9.00$, $z = 2.214$, $p < 0.05$ two-tailed. The effect size ($r = 0.67$) can be considered large (Cohen, 1988). The same test showed that there was no significant difference in average score for argumentation quality among advanced students across both tasks.

For the plant task, our data showed significant differences between novice and advanced students in terms of argument quality across tasks. Figure 2.2 shows that the advanced students demonstrated more sophisticated understandings of the molecular model for the plant task than the human task. However, no significant difference in their argumentation quality existed across tasks. It is possible that differences in content knowledge were not significant enough to generate an appreciable difference in argumentation quality among the advanced students. Figure 2.2 also illustrates that novice students demonstrated a wide variety of genetic knowledge across both tasks (from little/no knowledge to expert knowledge). Analysis of their argumentation quality suggests that novices provided significantly more complex arguments for the human task versus the plant task. For example, Angela, a novice student, provided the following opening arguments for the plant and human tasks:

Plant Task

Int — So if you were a member of the jury for this trial [patent infringement case], which way would you be leaning in terms of a decision?

Angela — 30% of his harvest were that type of corn, so it would seem kind of strange that such a big part of your field did get that pollination but what he's saying makes sense because I remember…we had problems, we actually did problems with the genetically modified corn and once planted the next generation and the next generation is also gonna show GM [genetically modified] corn.

Human Task

Int — So after hearing this story [paternity case], who's side would you be leaning towards?

Angela — I go with the mom. Not to say that right now I agree with the random mutation, but it is probable because albinism is not a very expressed condition. So it occurring, when the father says it couldn't possibly be in his line, I feel that he would not know. Just because of…or I don't think anyone would be able to tell because you can't trace it that much. The likeliness that it occurred in a generation that you would be able to track as of now, I don't think it's likely. So there is a possibility that it is within his line, he just doesn't know.

In this example, Angela provides a simple argument (level 2 - justification with simple grounds) for the plant task consisting of a claim and data gathered from the task prompt and her own knowledge of genetically modified organisms. In the human task, Angela provides a more structurally complex argument (level 4 - justification with elaborated grounds and a counter-position) demonstrating her knowledge of traits that can be carried and not necessarily expressed for many generations. It is possible that the varied levels of content knowledge about particular issues significantly affected argumentation quality across tasks for Angela and other novice students.

2.6 Discussion

The main purpose of this study was to explore how undergraduate students' use their genetic knowledge to support arguments about two distinct reasoning tasks. The findings of this study suggest that, for these participants, situational features of the tasks may influence reasoning especially when content knowledge is not well developed. This was especially apparent for novice students who demonstrated greater differences in reasoning across both tasks than the advanced students. This finding is supported by prior research that robust content knowledge is critical for generating well organized patterns of reasoning (Sadler & Fowler, 2006). However, the marked difference in reasoning across tasks may have more to do with the situational features of the task than with differences in content knowledge or argumentation ability. More specifically, we first explored the differences between novice and advanced students use of genetic content knowledge across two different reasoning tasks. During the interview, students were provided intensive opportunities to draw upon their content knowledge of genetics. Patterns of knowledge use were similar across both tasks for both advanced and novice students (Figure 2.1). Differences in situational features across tasks did not influence the types of content knowledge used by the students in generating their arguments. However, features of tasks did appear to influence students' argument quality, especially in the case of the novice students.

In order to characterize reasoning differences across participant groups and across tasks in this study, we applied the Threshold Model of Content Knowledge Transfer (Sadler & Donnelly, 2006) to our data, which hypothesizes a nonlinear relationship between content knowledge and argument quality. To demonstrate how students reasoned

for each task, we positioned students on the model based on average performance for each task. For the advanced students, knowledge use and argument quality were similar across both reasoning tasks; and, not surprisingly, more sophisticated in many instances than for the novice students. The advanced students applied the most sophisticated understandings of the molecular model for the plant task and with slightly less sophistication (22% fewer) for the human task. We speculate that differences in knowledge use may arise from the ability of the individual to construct a generalized schema of content knowledge and then use such information to solve novel problems (Author, 2007; Greeno, Collins, & Resnick, 1996). However, analysis of reasoning complexity demonstrated that the advanced students provided more detailed explanations of the molecular model than the novice students for both tasks. This suggests that advanced students' generalized schema was robust enough to transcend differences in situational features across these tasks. Therefore, using the Threshold Model as a framework, we placed the advanced students at the 'expert' level since their overall reasoning ability exceeded that of the novice students for both tasks (Figure 2.3).

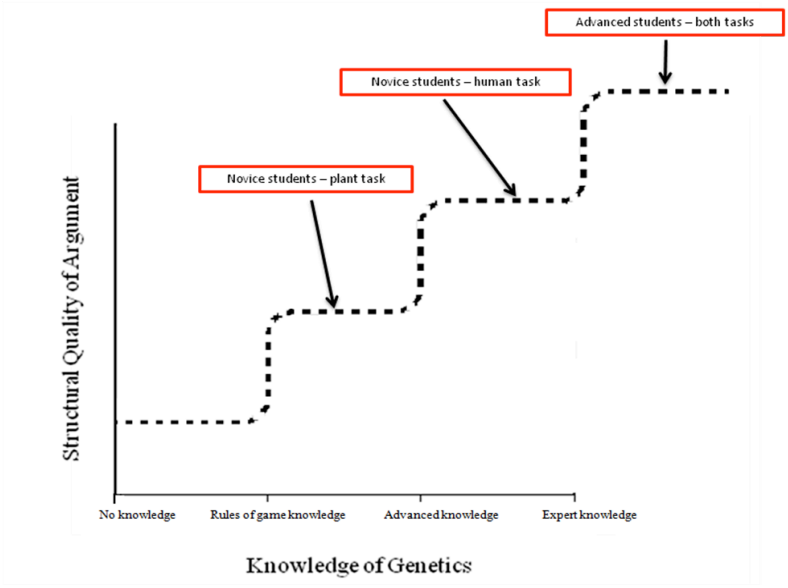


Figure 2.3. The threshold of content knowledge transfer adapted to include interpretations of our findings.

The novice students were more difficult to position within this model because of the varied sophistication of their content knowledge. This diversity made it difficult to determine if differences in knowledge use arose specifically due to situational features of each task. Like Nehm and Ha (2011) who found that students provided less robust biological explanations of evolution when asked to reason across issues, we also believe that the novice students' use of their knowledge, albeit the same underlying genetic knowledge was affected by the features of these tasks. This notion became more developed when knowledge use results were combined with students' argumentation abilities, which was the only component that significantly distinguished their overall performance. Novice students provided higher quality arguments for the human task versus the plant task. Although further study is required to determine how the features of these issues affect reasoning, we wonder whether novice students in this study were

distracted by superficial features, such as organism type, that could have diverted students from focusing on the underlying genetic principles of each task. We therefore positioned the novice students at the 'rules of the game' level for the plant task and at the 'advanced' level for the human task. The distribution of novice students' understandings suggests sub-thresholds of content knowledge may exist between the main thresholds identified in this study. However, the difference in argumentation quality for novice students supports the assertion that situational features can influence reasoning (Ceci & Ruiz, 1993; Chi et al., 1981; Nehm & Ha, 2011).

Our work extends the current literature by suggesting that specific situational features (e.g., type of organism) may promote more or less sophisticated reasoning across participants with less developed understandings in a domain. Results from other studies demonstrate that varying situational features of assessment items despite underlying knowledge principles being similar across items can influence how high school and undergraduate students reason (Heredia, Furtak, & Morrison, 2012; Nehm & Ha, 2011). Thus, the differences we observed among the participants in this study could be due to the situational features of tasks as knowledge requirements and prompts for argument generation were similar in nature across tasks.

Understanding how situational features influence individuals' reasoning is important to discern as such features are authentic components of socio-scientific issues individuals may encounter in their daily lives. What we do not yet know is *how* situational features influence reasoning and *to what* extent. Based on prior research in other science domains, it is likely that organism type (Author et al., 2011; Heredia et al., 2012; Nehm & Ha, 2011) does influence reasoning. However, other features such as

pathology, technology, or relationships between entities (e.g., role of the environment in gene expression) may contribute to different reasoning patterns across students with varying knowledge levels. Although the findings of this study appear straightforward and consistent with the research literature, we argue that the implications of this work (i.e., how and which specific situational features influence reasoning) bear merit and require further investigation.

2.7 Implications

Implications can be drawn from this work, however two limitations must be addressed. First, unlike other studies (Bowling et al., 2008; Sadler, 2003; Venville et al., 2005), we did not use any general assessments of genetic content knowledge. This study instead inferred knowledge of genetics based on participants' ability to reason within the interview tasks. We chose to discern content knowledge from the interviews rather than use a separate survey because we were interested in exploring how students used their knowledge of genetics to reason within the tasks, a process more closely resembling how individuals consider issues they encounter in their daily lives. A survey may capture what students know about genetics, but is limited in predicting how knowledge is used. It is also possible that argumentation differences exist across individual participants, but because of within group similarities we feel it is still appropriate to make inferences about the situational influences on argumentation quality within and across groups.

A second limitation of this work concerns sample size and homogeneity across groups. The sample size of twenty is small and thus these findings may not generalize to broader groups of students. The two groups of students were also not entirely homogenous. For example, the novice students' GPA's were lower than those of the

advanced students. Also, none of the novice students expressed interest in pursuing a genetics major. Interest in a particular domain, and even specific issues, can promote deeper learning of the material (Shimoda, White, & Frederiksen, 2002; Venville & Dawson, 2010). Since the novice students had limited experience with genetics, it is possible that they did not attend to the material as closely as the advanced students.

In light of these limitations, we present the following implications. First, this study and others support the notion that situational features can influence how individuals consider socio-scientific issues. The demand placed on the public to make informed decisions regarding genetics issues continues to rise. Reasoning about genetics issues is challenging for most individuals (Author et al., 2007; Author et al., 2011; Sadler & Fowler, 2006). This raises questions about the public's ability to participate knowledgeably in socio-scientific debates (e.g., in 2012, Californians considered Proposition 37 calling for all genetically modified foods to be labeled), and to provide informed consent for a variety of novel procedures (e.g., genetic screens and stem cell research). Thus, supporting students' literacy across a variety of distinct issues is important for generating citizens that can make informed decisions about complex social and scientific issues. It is critical to draw the development of argumentation skills about a variety of issues into the science classroom and place equal emphasis on these skills along with the development of content knowledge in order to prepare students for reasoning about issues they may encounter during their lifetime.

The second implication of this work points to the usefulness of distinct socio-scientific issues as teaching tools to improve students' genetics literacy. Recently developed science education initiatives (NRC, 2012) call for teaching practices that

support what students should know in science domains (core ideas), how these ideas relate to what scientists do (practices), and the coherence of disciplinary knowledge using organizational schema (cross-cutting themes). Classroom time and resources are often limited and development of robust knowledge and argumentation skills is not developmentally inevitable (Zohar & Nemet, 2002). Determining how students consider issues comprised of various situational features is also difficult to assess as students approach learning with varying domain expertise and reasoning skills. Despite these challenges, the use of situationally distinct examples of socio-scientific issues in the science classroom can support students' understanding of science in authentic ways, significantly improve students' analytical discourse, and improve students' ability to reason about complex issues (AAAS, 2011; Feinstein, Allen, & Jenkins, 2013; Jiménez-Aleixandre, Bugallo Rodríguez, & Duschl, 2000; NRC, 2011, 2012; Sadler & Fowler, 2006).

Chapter 3:

A content analysis of genetics news articles:

Exploring situational features and content knowledge requirements

for genetic literacy

Abstract

Genetic literacy is becoming increasingly important as advancements in our application of genetic technologies such as stem cell research, cloning, and genetic screening become more prevalent. Research shows, however, that many high school graduates lack the genetic knowledge necessary to participate in public debates over emerging genetic technologies. Few studies examine the kinds of genetic phenomena individuals encounter in their daily lives and the knowledge needed to reason about such issues. We present our findings from an inductive content analysis of genetics news articles from the *New York Times'* science section. Our analysis sought to characterize the situational features of genetics issues that arise most frequently across recent articles as well as the genetic content knowledge we anticipate as necessary to reason about featured issues. Overall, we found that situational features that arise most frequently describe a human pathology of a physiological nature identified or discerned by technological applications. From our content knowledge analysis, we anticipate that individuals need detailed knowledge of molecular mechanisms in order to reason about such issues. This work provides insights as to the conceptual obstacles and leverages involved in complex reasoning in the domain of genetics.

3.1 Introduction

Due to the rapid progress and development of scientific technologies in recent years, the public encounters science issues in their daily lives more frequently than ever before. Understanding and interpreting these issues is critical for meaningful engagement with science by the public. Media coverage (e.g., newspapers) is a one salient way by that the public encounters scientific issues (Jones & Himelboim, 2010; Leask, Hooker, & King, 2010). Newspaper headlines such as "Study links male infertility to a missing protein", "Altering a mouse gene turns up aggression, study says", and " Canola, pushed by genetics, moves into uncharted territories", demonstrate the diversity of phenomena presented to the public and the pressing need for scientific literacy for all individuals. This begs the question: *What kinds of phenomena arise that challenge public understanding, and what content knowledge do individuals require in order to understand phenomena presented in these articles?*

Determining the diversity and prevalence of phenomena is particularly acute for domains that advance rapidly. One such domain is genetics. Research in genetics has made tremendous strides with developments such as cloning, gene therapy, and genetically modified organisms, etc. Public understanding of the societal benefits and repercussions of these genetic advances are becoming increasingly important for both personal and civic engagement. Now, more so then ever before, genetic technologies are accessible to the public without the need for expert interpretation. For example, private companies such as 23andMe offer affordable genetic testing to the public without the requirement of a genetic counselor or geneticist to interpret the results of such tests for the consumer (23andMe, 2012). For the lay person who does not fully grasp genetics

concepts (i.e., heritability) or has difficulty interpreting probabilities (i.e., percent chance of developing a genetic disorder), test results may be interpreted in ways that are misinformed (Bellcross, Page, & Meaney-Delman, 2012; Hawkins & Ho, 2012). This may result in poor decision making about high stakes issues (e.g., whether or not to pursue further screening for breast cancer if test results suggest low likelihood of development). These and other examples raise questions about the public's and students' ability to participate knowledgeably in socio-scientific debates (e.g., stem cell research, genetically modified foods), and to provide informed consent for a variety of novel procedures (e.g., gene therapy, genome screening).

Science education is a starting place for many interventions seeking to foster scientific literacy among students. However, the underlying assumption of schooling, that students can develop generalized knowledge of core concepts and they can thus reason equally well about diverse phenomena (when the underlying scientific principles are the same), is proving to be problematic (Bransford & Schwartz, 1999). Not only are phenomena wide ranging in terms of topic, they can also present a variety of situational features that may challenge individuals' reasoning abilities. By "situational features" we mean the summation of defining characteristics of an issue used to describe a particular phenomenon that may elicit different reasoning strategies and sophistication based on an individual's current understandings (i.e., what they already know about the phenomenon) in combination with information that can be drawn from the presentation of the phenomenon (i.e., what background information is provided in the news article). For example, one situational feature considered in this study is type of organism (taxon). Articles discussing genetic phenomena often feature an organism about which the story is

developed. Studies demonstrate that students generally provide more robust reasoning strategies with greater sophistication when asked to consider phenomena about humans versus plants or bacteria despite the underlying content knowledge being similar (Freidenreich, Duncan, & Shea, 2011; Shea, Duncan, & Stephenson, 2011; Watts & Bentley, 1994). This is likely attributable to the anthropocentric presentation of scientific information in K-12 classrooms and students familiarity with phenomena about humans versus other organisms (Watts & Bentley, 1994). It is probable that other situational features exist that generate a similar effect in terms of eliciting more or less sophisticated reasoning strategies depending on the individuals prior knowledge. This may become problematic for individuals when they are required to consider phenomena comprised of situational features of which they have little or no knowledge, especially in regard to high-stakes decisions (e.g., interpreting genetic test results).

Very few studies attempt to identify the situational features and anticipated knowledge requirements support the presentation of genetic phenomena (Heredia, Furtak, & Morrison, 2012; Nehm & Ha, 2011). In this study, we performed an inductive content analysis of genetics new articles to determine the kinds of situational features that arise frequently and to identify the underlying knowledge of genetics that we anticipate is required to understand the main ideas in the articles. Specifically, we sought to address the following research questions:

1. What kinds of issues and corresponding situational features that support genetic phenomena arise in news articles?
2. What genetic knowledge is likely required in order to understand the phenomena presented in the articles?

3.2 Literature Review

3.2.1 Situational Features and Reasoning

A productive line of research that specifically identifies situational features that influence reasoning is that of assessment item features and their association with knowledge use. Assessment items are particularly useful for studying the effects of situational features on reasoning because they can be tailored to the types of features of interest. For example, in physics, assessment items requiring the use of the same underlying equations but differing in terms of physical features described in the item (e.g., pulleys versus ramps) evoke different knowledge use and application between novice and expert learners (Bryce & MacMillan, 2009; Chi et al., 1981).

In evolutionary biology, Nehm & Ha (2011) examined undergraduate students reasoning about evolution assessment items demonstrating different situational features. Nehm and Ha (2011) characterized assessment items by subdividing situational features into specific features such as *units* (e.g., comparisons within or across species), *taxa* (e.g., plants, bacteria, animals, etc), *traits* (e.g., eye color, fur color)*, character state polarity* (gain or loss of traits)*, explanations and predictions* (e.g., initial/final state is provided and explanation or prediction is requested). By designing matched pairs multiple choice items that differed in one feature and held others equivalent, they were able to observe differences in reasoning due to specific situational features. Nehm and Ha (2011) found that a significantly greater number of naïve conceptions about tasks that asked undergraduate students to reason about trait loss versus trait gain in animals and plants. The same underlying evolutionary principles explain both kinds of physical changes. However, students had difficulty developing scientific explanations for trait loss both

within species and across different species since evolutionary examples provided in textbooks and curricular materials generally consider the gain of traits versus their loss (e.g., trait loss examples included loss of eyes in salamanders, loss of thorns on roses, and loss of flight in birds; trait gain examples included gain of running speed in cheetahs, gain of resistance in locusts, and gain of poison in plants).

Building on this work, Heredia, Furtak, and Morrison (2012) explored how high school students responded to multiple choice items about natural selection. The authors designed matched pairs items with similar underlying evolutionary principles, yet differing situational features (e.g., perceived aggressive versus friendly animals, and animal versus plant). They found that students were more likely to choose correct answers for items that matched their ideas about an organism's behavior. For example, students believed koala bears are more likely to produce fertile offspring than rattlesnakes (Heredia et al., 2012). This may be because students projected their ideas of sociability and the organism's fitness onto more "friendly" animals versus "aggressive" animals. However, when students were challenged with items about trait variation across multiple organisms, students differed very little in their responses - possibly because students applied their knowledge of trait variation independent of which organism was featured. In this case, it may be possible that some situational features figured prominently in students' problem solving, while other features had limited influence. Together, Nehm and Ha's (2011) and Heredia et al's. (2012) studies make tangible the critical effect situational features can have on how individuals' approach and solve problems. Thus, Nehm and Ha (2011) conclude that situational features are "a significant contributor to how people perceive, use, internally represent, and solve problems" (p. 239).

3.2.2 Familiarity with Situational Features

Knowledge alone is not indicative of how an individual will generate a solution to a problem comprised of specific situational features. Resources available to individuals (e.g., past learning experiences, social interactions, etc) and beliefs or opinions about an issue can contribute to one's reasoning ability (Barnett & Ceci, 2002; Duranti & Goodwin, 1992; Lewis & Leach, 2006). For example, the phenomenon of situationally-based reasoning differences was also observed in a study of 200 high school students conducted by Lewis and Leach (2006). The authors found that scientific knowledge and familiarity with topics significantly contributed to students' ability to reason about phenomena comprised of different situational features. Leach and Lewis (2006) found that student pairs had difficulty reasoning about phenomena comprised of unfamiliar situational features such as genetically modified oil-eating bacteria versus those more familiar to them such as the generation of genetically modified pest-resistant crops. Each issue included the same underlying technology, genetic modification, but varied in terms of the feature taxa (bacteria versus plants). Thus, familiarity with specific taxa, in this case, contributed to students' reasoning.

In the our own work (Shea, Duncan, & Stephenson, 2011), we also observed situationally-dependent reasoning differences when we asked undergraduate science majors (those beginning and those ending their academic careers) to consider authentic genetic dilemmas. We provided students with two reasoning tasks - one about genetic modification of corn and one about the likelihood of inheriting a genetic skin pigmentation disorder (albinism). The two tasks differed in terms of the feature taxa (plants versus humans). Despite these differences, both tasks required use of the same

genetics concepts about molecular genetics. We found that late career undergraduates (juniors and seniors) generated arguments about each task that were equally well developed in terms of structural quality and use of molecular genetics knowledge. However, the early career undergraduates (freshmen and sophomores) developed similarly high quality arguments for the task about a human genetic disorder (albinism) versus the task about plant genetic modification.

It is likely that familiarity with specific situational features (e.g., humans more so than plants) contributed to differences in reasoning ability, especially for the early career students in our study. Research suggests that children and adults alike tend to think of the world in anthropocentric terms due to the presentation of scientific concepts with greater emphasis placed on human issues, that may explain this finding (Watts & Bentley, 1994). It is likely that the late career students performed equally well on both tasks due to the knowledge they gained from advanced course work, that likely exposed them to a variety of situational features in molecular genetics.

In addition, questions posed in our study prompted students to consider molecular mechanisms (i.e., describing the underlying casual mechanism of a phenomenon) which is often difficult for most students (van Mil, Boerwinkel, & Waarlo, 2011), especially those with limited exposure to such issues. Marbach-Ad and Stavy (2000) suggest that such mechanistic reasoning is challenging for individuals for two reasons. First, mechanistic reasoning entails knowledge of the main organizational levels that support the phenomenon: macroscopic (organismal), microscopic (cellular), and submicroscopic (biochemical); and second, mechanistic reasoning is challenging because individuals require familiarity with biological components of genetic mechanisms (i.e., how genes

relate to proteins, and how proteins bring about traits). Without knowledge about molecules, such as proteins and their central role in genetic mechanisms, individuals will struggle to productively reason about complex genetic phenomena (Duncan & Reiser, 2007).

The research presented thus far suggests that situational features influence reasoning, whether considering multiple choice items, open-ended questions, or diagnostic exercises. Questions remain about the specific situational features that matter most in terms of influencing reasoning, to what extent familiarity with features plays a role in reasoning, and how transfer of knowledge is influenced by such features. Given the effects of situational features shown above, it is important to develop better understandings of how and what kinds of features are prevalent in everyday encounters with science issues, such phenomena presented in news articles. Equally important is identifying the kinds of knowledge needed to reason about the phenomena presented in such articles to better support public understanding of and engagement with scientific issues. It is also likely that a better understanding of the kinds of situational features prevalent in news articles can help educational researchers and practitioners tailor instructional activities to support and develop students' reasoning about current topics in science. This study is one of few that applies empirical methods for identifying situational features and anticipated knowledge requirements in genetics. In addition to characterizing situational features that may influence reasoning - as exemplified in prior research - this study reaches beyond laboratory and classroom experiments and explores authentic issues presented in news articles - those the public is very likely to encounter in

their daily lives - thus providing a deeper understanding of anticipated knowledge requirements necessary for engaging in reasoning about current scientific issues.

3.3 Theoretical Framework

Members of the lay public "do not, for the most part, seek to become scientific insiders… [instead] they remain anchored outside of science, reaching in for bits and pieces that enrich their understanding of their own lives" (Feinstein, 2011, p. 180). The field of genetics is one example of a domain where individuals are likely to seek such enrichment, especially in the wake of recent advancements in genetic technologies that increasingly encroach on the public sector (e.g., direct to consumer genetic test kits). We have a limited understanding of what kinds of issues the public is likely to encounter regarding genetics and the content knowledge they require in order to understand such issues. We turn our attention to news articles as one salient source of information the public draws on to learn about genetics issues, since news articles provide an salient means for identifying recurrent topics (i.e., news articles present genetics issues that are actually occurring in the world).

In this study, we take a finer grained approach for characterizing issues by defining their situational features as we analyze events occurring within news articles. Situational features, in this study, are embodied by the stories presented in the news articles (i.e., the unit of analysis in this study). We were interested in closely examining situational features presented in news articles - a common way the public engages with science issues - in terms of presumed knowledge requirements since content knowledge is essential for understanding the focal event in each story and a major component of scientific literacy. To characterize the issues presented in the news articles, we focused

on two main aspects: (a) content knowledge (e.g., specific aspects of domain-specific knowledge presented in the story) and (b) language (e.g., what key words, phrases, and propositions are used to convey scientific concepts in the story). Similar to Nehm and Ha's (2011) work in evolutionary biology and Heredia et al's (2012) work in natural selection, we attempted to characterize genetics issues in terms of specific situational features that align with genetics concepts necessary to understand the phenomena presented.

To guide our investigation of situational features and anticipated knowledge requirements, we drew on prior research that underscores issues in genetics education. Specifically, we drew on the work of Duncan, Rogat, and Yarden (2009) who recently developed a genetics learning progression - an extended cognitive model developed to promote deeper conceptual understanding of genetics. Learning progressions have been advocated by the National Assessment of Educational Progress (NAEP, 2006) and the National Research Council (NRC, 2005, 2007, 2011, 2012) as a means for aligning curriculum, instruction, and assessment in science. These progressions focus on a limited number of core ideas over the course of years, that progress in sophistication and level of complexity. Developing the core ideas embedded in a progression does not occur naturally and therefore requires targeted instruction, curriculum, and assessment.

The genetics learning progression makes conjectures about what concepts are needed to be genetically literate and at what level of sophistication. Duncan, Rogat, and Yarden (2009) base their learning progression on the work of Stewart, Cartier, and Passmore (2005) who identified three models of genetics knowledge that they argue comprise genetics literacy; (a) the genetic (or inheritance) model, that describes the

pattern of inheritance between parents and offspring, (b) the meiotic model that describes the passage of genes from parent to offspring through sperm and egg, and (c) the molecular model that describes how genes are translated into proteins that bring about physical traits. Thus, this study employs empirical methodology (content and task analyses) to investigate the kinds of issues and corresponding situational features that are commonly portrayed in news articles and to characterize the genetic content knowledge (implicated in the genetics learning progression) presumably needed to reason about such issues.

3.4 Methods

3.4.1 Study Context

To determine the kinds of genetic issues and corresponding situational features that arise frequently in the mainstream media, we conducted a retrospective survey of the *New York Times'* science section from 2010-2011. The *Times'* is a national paper that ranks third in terms of circulation with just under one million copies sold each week day (Associated Press, 2010). Since 1917, the *Times* won 106 Pulitzer Prizes, regarded as the most prestigious award for newspaper and online journalism (Perez-Peña, 2009). Therefore, the *Times* is a newspaper with which many members of the public are familiar, and the science section is a rich source of articles concerning genetics issues.

3.4.2 Data Collection

To collect a corpus of articles, we conducted a keyword search using the *Times'* online database for the terms *gene*, *genetics*, *protein,* and *DNA*. Approximately 200 articles were identified that contained one or more search terms. We classified the data corpus by applying a framing typology coding scheme developed by Nisbet, Brossard,

and Kroepsch (2003). Although Nisbet et al.'s search focused specifically on stem cell research in the media, the same framing typologies can be applied to the field of genetics more broadly construed. Within the typologies they identified, those with a focus on the presentation of new research, the presentation of scientific background information supporting new research findings, and the presentation of scientific controversy regarding research findings and scientific theories were used to narrow the population of articles in this study (Table 3.1). These frames were selected since they emphasize scientific content knowledge, and focus less on issues such as political agenda, religious views, or public opinion that often emphasize social implications of genetic research with limited information pertaining to the actual science behind the issue. The final data pool was reduced to 104 articles across both years.

Table 3.1.
Framing topologies adapted from Nisbet, Brossard, and Kroepsch (2003), p. 49

Frame	Description
New Research	"Focus on new [genetics] research released, discovery announced, new medical or scientific application announced, clinical trial results announced. Includes government study, scientific journal article, scientific meeting paper, science-by-press conference".
Scientific Background	"Focus on general scientific or medical background of [genetics] related research or applications. Includes description of previous research, recap of 'known' results and findings, description of potential medical applications/uses".
Scientific Controversy	"Focus on scientific uncertainty over efficacy or outcomes of [genetics] related research and applications, uncertainty over when [genetics] derived applications will be available or in use, dispute over medical or scientific advantages" or disadvantages as a result of such technologies.

3.4.3 Data Analysis

To answer the first question about the types of issues and corresponding situational features that are prevalent in the articles, we began by performing an inductive

content analysis. Content analysis refers to “a research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns” (Hsieh & Shannon, 2005, p. 1278). This form of an inductive approach, therefore, begins with a highly detailed and specific analysis of data and moves to a broader, more general set of conclusions. Such an approach was appropriate for this study for two reasons: (a) situational features - as defined in this study - are captured within the content of the article, and (b) we have very little knowledge of the kinds of genetic issues and their corresponding features that arise in current news articles.

Our inductive content analysis focused on identifying the situational features that arise most frequently in the articles. We began by identifying sentences that contained terms and phrases relevant to genetic knowledge in each article. For example, in an article about individuals with a rare genetic disorder that inhibits the formation of fingerprints (i.e., Adermatoglyphia), the following sentences were identified as containing key ideas relevant to genetic content knowledge: "The researchers found that the affected members of the family all had a mutation in the gene called Smarcad1. Specifically, they had this mutation in a version of the gene that is expressed only in skin" (Bhanoo, 2011, p.1). This pair of sentences was chosen as a key proposition because it directly referenced ideas relevant to molecular genetics, such as gene mutation, versions of genes, and gene expression, that became the codes we employed to characterize the situational features supporting the phenomena in each article. Specifically, we developed codes to identify recurring situational features presented in the articles (Table 3.2). For example, using the fingerprints article as representative of the

articles we analyzed, the story featured a *type of organism* (human), a *pathology* (no finger prints), and discussed genetics concepts at different *levels of organization* (i.e., at the sub-cellular level (genes/proteins) and at the trait level (no fingerprints)). Together these three situational features characterized the issue presented in the article. Other articles also included the features of *genetic technologies* (e.g., gene therapy, genetic modification). It is important to note that these features are not mutually exclusive. Some appear in all articles, while others appeared in only a subset of articles. Many articles presented at least two features within the body of the article.

Table 3.2.
Situational features and their descriptions from inductive analysis of news articles

Situational features	**Description**
Organism	Specific organism featured in the article – may be more than one.
Levels of Organization	Relationship between macroscopic (organismal), microscopic (cellular), and submicroscopic (biochemical) levels (e.g., Mutations in genes that regulate cell division lead to cancer).
Genetic Technologies	Description of the technology used to manipulate genes, DNA, or traits (e.g., Genetic mutations purposefully introduced into plant embryos provide herbicide resistance).
Type of Pathology	Description of the symptoms as a result of a particular genetic disorder (e.g., Mutation in the gene linked to Cystic Fibrosis causes thickening of mucus layer in lungs).

Once situational features were identified, these were further parsed into sub-features presented in the articles. For example, the feature *types of organism* was parsed into five sub-features: human (as in the fingerprints article), mammals, non-mammals (e.g., insects, reptiles, birds), plants, and bacteria. We continued this process with each situational features based on the those that emerged in the articles. Finally, we conducted a frequency count of features and sub-features found in the articles. Analysis of

situational features and sub-features was performed with all articles from 2011 (n = 58). We chose not to continue our analysis with the 2010 articles since situational features and sub-features became highly repetitive with the 2011 data set. Three coders analyzed all of the data to reach consensus.

To answer the second research question about the kinds of knowledge needed to understand the main points of the articles, we performed a second inductive content analysis of each article. Using a genetics learning progression developed by Duncan, Rogat, and Yarden (2009) we focused our analysis on identifying concepts in the articles (from both years, n = 104) that ascribe to big ideas in genetics as identified by the learning progression. In their development of the learning progression for middle and high school students, Duncan, Rogat, and Yarden (2009) describe eight big ideas that students should know in order to develop robust understandings of the domain (Table 3.3). These big ideas reflect core understanding in genetics needed to reason about the three models in genetics (Duncan, Rogat, & Yarden, 2009). Each big idea is described in three levels of sophistication that build on each other as students progress from late elementary into the middle and high school grade bands.

Table 3.3.
Eight genetics knowledge themes (Duncan, Rogat, & Yarden, 2009)

Theme	Description
A	All organisms have genetic information. All genetic information is hierarchically organized.
B	The genetic information contains universal instructions that specify protein structure.
C	Proteins have a central role in the functioning of all living organisms and are the mechanism that connects genes and traits.
D	All cells have the same genetic information, but different cells use (express) different genes.
E	Organisms reproduce by transferring their genetic information to the next generation.
F	There are patterns of correlation between genes and traits and there are certain probabilities with which these patterns occur.
G	Changes to the genetic information can cause changes in how organisms look and function.
H	Environmental factors can interact with organisms' genetic information.

Since the genetics learning progression is the most detailed theoretical analysis of required genetic knowledge in the current research literature, we adopted the eight big ideas (and three levels of sophistication per theme) for the purposes of our own work. Using the learning progression as a guide, we developed an iterative coding scheme that reified the three levels of sophistication for each of the eight big ideas. In general, each level described a specific level of organization explaining the genetic phenomenon in increasing detail: (a) level 1 for each big idea consisted of an explanation at the organismal level (i.e., describing observable traits), (b) level 2 for each big idea consisted of explanations at the cellular level (i.e., how cells are affected by genetic changes), (c) level 3 for each big idea consisted of explanations at the molecular or biochemical level (i.e., what is happening to the genes, proteins, chromosomes).

As we conducted our analysis of the articles, it became apparent that a fourth level was required for six of the eight big ideas. This fourth level was somewhat different from the preceding three in that it did not add another level of organization, ideas at level 4 were also molecular in nature, but instead captured more detailed expert level knowledge in general and considered concepts not included in the learning progression due to their complexity (i.e., these concepts exceeded knowledge expectations for middle and high school grades). For example, for big idea B (genes as instructions for protein structure) level 3 includes the concept that genes are instructional in nature and code for physical entities - proteins - that carry out specific functions in organisms. Level 4 for this big idea emphasizes the *processes* by which genetic instructions are translated into proteins that bring about observable traits. These processes (transcription and translation) occur at the molecular level and involve specific molecular machinery (genes and various proteins). The details of how genes are transcribed and translated into proteins is not included in the genetics learning progression, but were discussed in the articles. Thus, it was important to include a fourth level for this big idea as well as for others where more detailed descriptions of genetic phenomena were discussed in the articles.

Using the learning progression as a guide, we coded each article according to types of big ideas presented in the body of the article and the level of sophistication for each big idea that we anticipated is required to understand the key ideas. Codes for each article were then compared to determine which big ideas of content knowledge are most frequently required to understand genetics articles and at what level of sophistication. Half of the data was coded by two independent raters. Inter-coder reliability was 91% for this part of the inductive content analysis.

3.5 Results

3.5.1 Examining Situational Features

In addressing the first research question about the kinds of issues that arise most commonly within genetics news articles, we found four distinct situational features across articles: *type of organism* featured (e.g., human, plant, bacteria), *level of organization* (i.e., biochemical, cellular, and organismal), *type of pathology* (e.g., Parkinson's disease) and *genetic technologies* (e.g., gene therapy, genome mapping). For example, the following propositions from an article about genetically inherited hemophilia (Wade, 2011a) illustrate these features:

Selected propositions	Situational features
Medical researchers in Britain have successfully treated six [human] patients suffering from the blood-clotting disease known as hemophilia B by injecting them with the correct form of a defective gene, a landmark achievement in the troubled field of gene therapy.	*Type of organism* (human patients) *Type of pathology* (hemophilia B) *Level of organization* (Organismal: humans have a blood-clotting disorder)
The general concept of gene therapy — replacing the defective gene in any genetic disease with the intact version — has long been alluring.	*Genetic technology* (gene therapy)
Dr. Nathwani and his team reported that they treated the patients by infusing the delivery virus into their veins. The virus homes in on the cells of the liver, and the gene it carries then churns out correct copies of Factor IX [a protein].	*Level of organization* (Cellular: a virus carrying the correct form of the gene is introduced into liver cells that now create the correct protein for clotting; Molecular: Factor IX, a protein needed for clotting, is produced by the correct form of the gene)

These features characterize the issues embodied in the news articles. This approach for defining issues focuses on framing phenomena as they are portrayed in the news (i.e., what content knowledge is emphasized, what processes or practices take place in the story, and what language is used to communicate concepts and provide meaning to the phenomenon).

Across all articles from 2011 (n = 58), the two features *type of organism* and *levels of organization* occurred consistently in each article (Table 3.4). Considering the articles we surveyed concern biological issues - those about genetics specifically - it is not surprising that at least one type of organism be featured within each article and the events described at some level of organization. *Type of pathology* and type of *genetic technologies* were also commonly presented within articles, but not consistently across all articles (Table 3.4).

Table 3.4.
Situational features in 2011 news articles, and their frequencies

Situational Features	**% Article Features**	**Sub-features**	**% Article Sub-features**
Organism	100%	**Human**	**60%**
		Mammal	16%
		Non-mammal	22%
		Plants	7%
		Bacteria	12%
Levels of Biological Organization	100%	Organismal	2%
		Organismal, Biochemical	**72%**
		Organismal, Cellular, Biochemical	25%
Genetic Technologies	60%	Gene therapy	11%
		Ancient DNA reconstruction	5%
		Gene sequencing	**68%**
		Genetic engineering (e.g., GMO's)	16%
		Comparisons of genetic sequences	19%
Type of Pathology	50%	Cancers	16%
		Neurological (e.g., Alzheimer's)	20%
		Physiological (e.g., hemophilia)	**36%**
		Viral/Bacterial (e.g., Pneumonia)	12%

Aside from determining the specific situational features that arise, we also determined the type and frequency of specific sub-features. We found that each feature could be parsed into several sub-features, with one sub-feature occurring with greater frequency than the others in all cases. For *type of organism*, 60% of articles featured

humans; for *levels of organization*, 72% of articles discussed events both at the biochemical and organismal levels; for *types of pathology* 36% of articles featured a physiological disorders (a catch all category including disorders such as anemia, hemophilia, infertility, obesity, etc.); and for *genetic technologies*, 68% of articles featured gene or entire genome sequencing. This analysis demonstrated that the most prevalent issue includes an anthropocentric story describing the use of genome sequencing described at the biochemical and organismal levels to identify and characterize a genetic disorder of a physiological nature.

In addition, we also found that 42% of the articles, presented all four situational features (Table 3.5). Articles that presented all four situational features often included a story in which a genetic technology (e.g., gene therapy) was used to ameliorate a defective gene (e.g., biochemical level of organization) in an organism (e.g., humans) in order to reverse the symptoms (e.g., organismal level of organization) of a genetic disease (e.g., type of pathology). Articles that featured genetic technologies without pathology or vice versa were also common (38% and 20% respectively). In these kinds of articles, emphasis was placed on explaining the genetic technology and its use or explaining how a disease resulted from a genetic mutation. Identifying this issue and its situational features is helpful for predicting what kinds of genetics issues individuals are likely to encounter in their daily lives. We next sought to determine knowledge requirements we anticipate as critical for understanding genetics phenomena characterized by these situational features.

Table 3.5.
Frequency with which most common situational features *occur together across 2011 articles. Org = Organism, LoOrg = Levels of organization, Path = Types of pathology, Gen Tech = Genetic technologies.*

Situational Features	Frequency Across 2011 Articles
Org, LoOrg, Path	20%
Org, LoOrg, Gen Tech	38%
Org, LoOrg, Path, Gen Tech	**42%**

3.5.2 Determining Knowledge Requirements

To answer the second research question about anticipated knowledge requirements, we coded the articles using the eight big ideas of genetic content knowledge identified in Duncan, Rogat, and Yarden 's (2009) genetics learning progression (Table 3.3). Not every big idea of the eight proposed in the learning progression was represented in every article. Figure 3.1 illustrates the frequency of big ideas across the articles (more than one big idea was present in most articles).

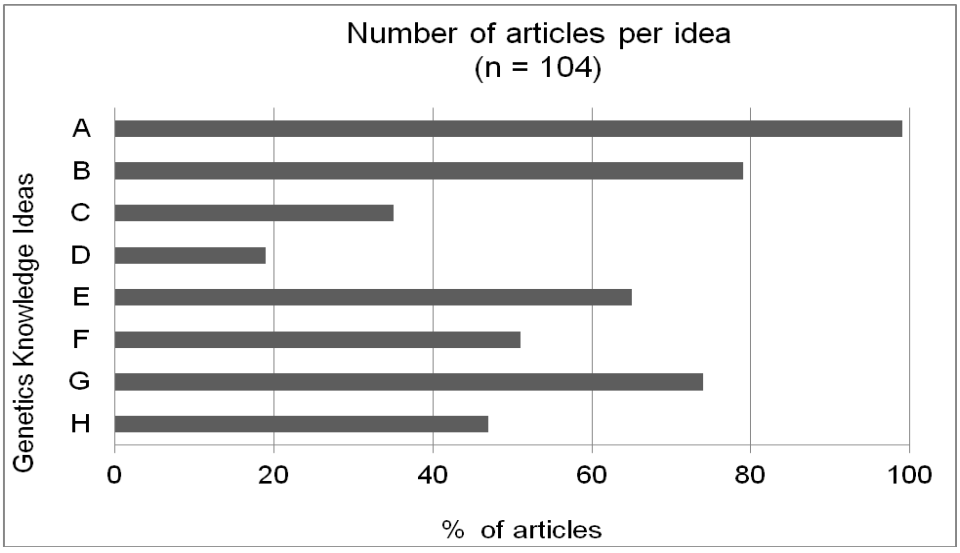


Figure 3.1. Frequency of articles invoking the eight genetics knowledge themes.

Ideas A - how genetic information is physically organized in a hierarchical manner, B - genes as instructions for making physical entities, usually proteins, E - how genetic information is inherited from one generate to the next, and G - how the sequence of genetic information can be changed (i.e., mutated) and may result in physical problems for the organism, were represented with the greatest frequency across all articles. These ideas map onto the situational features previously identified as they discuss concepts of genetic mutation and organization of genetic information, so it is understandable that Ideas A, B, E, and G arise most often within the articles. For example, Idea G focuses on concepts about genetic mutations. This idea directly maps onto the situational feature *Type of pathology* because genetic disorders arise due to changes to gene sequences (i.e., mutations in specific genes or sets of genes).

3.5.2.1 Levels of organization.

Ideas C - the concept that proteins are central for explaining the underlying mechanisms of a genetic phenomenon, D - the concept that all cells have the same genes, but express genes differently depending on cell type and function, F - how patterns of trait expression are correlated with gene expression and the probabilities with which these patterns are likely to occur, and H - how the environment interacts with genes to influence expression patterns, were represented in less than half of the articles. Ideas C, D, F, and H are less likely to map onto the situational features previously identified. For example, Idea H focuses on how the environment can influence gene expression patterns. This phenomenon is often referred to as epigenetics - a relatively new branch of genetic research that explores how gene expression patterns are influenced by factors other than changes to the sequence of DNA itself (e.g., environmental factors, such as exposure to

radiation, can alter chemical levels in an organism's cells that affect gene expression patterns thus producing an outcome for an organism different than typically expected). Processes requiring highly technical and sophisticated understandings of genetics - such as events leading to different gene expression patterns - were not typically discussed in the articles. Thus, big ideas supporting molecular explanations were less likely to arise.

For each theme of the genetics learning progression, Duncan, Rogat, and Yarden (2009) detailed three levels of knowledge sophistication. We included these levels in our own coding scheme, but added a fourth level since we found that some ideas presented in the news articles were more complex and required deeper understandings than proposed by the highest level in the learning progression. We gave ideas a level score from 1 – 4, with level 1 representing the least detailed knowledge for the corresponding big idea and level 4 representing the most sophisticated knowledge. Across all articles, Table 3.6 illustrates the percentage of the four levels of knowledge sophistication for each big idea.

Table 3.6.
Frequency of knowledge sophistication levels per theme across all articles.

		Genetics Knowledge Ideas							
		A	B	C	D	E	F	G	H
% Levels per Idea	Level 1	37	24	11	10	**88**	**53**	11	39
	Level 2	11	21	17	**80**	3	23	39	2
	Level 3	**43**	**54**	**69**	10	6	24	9	**59**
	Level 4	7	1	3	0	3	0	**41**	0

Although almost all big ideas entailed understanding at all four levels of knowledge sophistication, some levels are more prevalent than others for each big idea (in bold for each idea). This distribution of levels serves as the basis for what we anticipate as the most needed knowledge to understand subsequent big ideas. For those

big ideas that occur most frequently (A, B, E, G), we found that more sophisticated levels of understanding, levels 3 and 4, are commonly entailed in understanding the big ideas represented in the articles. The only exception to this is for theme E (genetic inheritance) in which the least sophisticated understanding - that genes are passed from parent to offspring (level 1) - was most prevalent (Table 3.7). For those themes that occur less frequently (C, D, F, H), we found variation in level sophistication.

Table 3.7.
Anticipated knowledge required per theme

Theme	Level	Anticipated Knowledge Required
A	3	Genome is the corpus of genetic information for an organism. No specific mention of DNA, chromosomes, or genes required.
B	3	Genes are instructions for molecules (many of which are proteins) that carry out functions within the organism. All organisms use the same genetic language for their instructions.
C	3	Proteins perform specific functions in the cells or in the body (e.g., protein function is dependent upon their structure). Specific examples given of how protein function (or lack of function) contributes to the genetic phenomena.
D	2	All cells have the same genetic content, but what genes are used by the cell (expressed) is regulated.
E	1	All organisms reproduce and transfer their genetic information to their offspring. In sexually reproducing organisms each parent contributes half the genetic information to the new generation.
F	1	We vary in how we grow and function. For a given trait there are variations. Different organisms have different versions of the trait.
G	4	DNA mutations are the source of genetic variation. Some DNA sequences can vary between species while others do not, therefore, we share some genes with other species (mice, flies) AND/OR DNA sequences can vary between individuals or sub-populations and allow us to differentiate between individuals or sub-populations.
H	3	Environmental factors can cause mutations in genes, or alter gene expression.

For the most part, the sophistication of knowledge levels corresponds with middle and high school science curriculum as levels 1 - 3 map onto genetics learning expectations for middle and high school grades. However, in the case of themes E (patterns of inheritance) and F (correlation between genes and traits), the most prevalent level of knowledge sophistication did not exceed the most basic understanding (level 1), that challenges the expectations of the genetics learning progression. In most articles, however, notions of

inheritance did not exceed that basic concept that genes are passed from parent to offspring. For example, in an article about the migratory pathways of ancestral humans, Wade (2011b) writes "The common variations in the human genome were mostly present in the ancestral human population in Africa and have been inherited by all the descendant populations around the world" (p. 2). In this excerpt, the notion of genetic inheritance is limited to simply passing genetic information from one generation to the next culminating in the human genetic variations observable today. This level of understanding represents what is commonly discussed in most articles regarding inheritance and falls short of what is expected by the learning progression - Level 3 - that focuses on the processes that underlie genetic variation and inheritance, specifically meiosis.

In the case of big idea G (how changes to genetic information can influence structure and function of an organism), the most prevalent level of knowledge sophistication exceeded the expectations of the learning progression (level 4). Level 3 for big idea G (from the learning progression) focuses on the molecular changes that can occur in one organism to explain differences in traits. We included a fourth level - most prevalent for idea G within articles - for this big idea that requires understanding that genetic mutations are the source of variation between individuals and between species. Also, that some gene sequences vary between species while others are shared, thus allowing for replacement of genes in one organism from another organism of a different species. This concept is exemplified in the following excerpt from an article about testing organisms' ability to sense magnetic fields for the purpose of navigation during migration events:

"[Dr. Reppert] then showed that the monarch butterflies' two cryptochrome genes could each substitute for the [fruit] fly's gene in letting it sense magnetic fields, indicating the butterfly uses the proteins for the same purpose. One of the monarch's two cryptochrome genes is similar in its DNA sequence to the human cryptochrome gene. That prompted the idea of seeing whether the human gene, too, could restore magnetic sensing to fruit flies whose own gene had been knocked out. In the journal Nature Communications, Dr. Reppert reports that this is indeed the case. " (Wade, 2011c, p. 1).

This excerpt demonstrates how researchers can manipulate the genes of organisms in order to determine their function. Identifying a magnetic field sensing gene (cryptochrome gene) in one organism (monarch butterfly) and substituting the gene in a different organism (fruit fly), demonstrated that the gene has identical functions in both organisms. Understanding that genes can share similar sequences across different species is a critical basis for explaining why species share similar capabilities and how they are genetically related to one another. The article extends this concept by indicating that a similar gene, found in humans, also produces the same effect in fruit fly suggesting that humans too possess magneto-sensitivity. This excerpt demonstrates how knowledge of gene relatedness between species (level 4 for idea G) is important for understanding how scientists explain genetic relationships within and across species.

3.6 Discussion

The purpose of this study was to identify and characterize the kinds of genetics issues that arise in news articles and to anticipate the kinds of the genetics knowledge one would need in order to understand the main ideas in the articles. In this study we

specifically focused on the phenomena depicted in genetics news articles and the knowledge required to understand such phenomena. We chose to set aside the ethical, historical, and sociological aspects that are often discussed in science literacy research and to instead focus on the genetic content knowledge we anticipate as necessary to understand issues since domain knowledge is often a limiting factor for individuals' understanding of genetics phenomena portrayed in the media (Bates, 2005; Donovan & Venville, 2012; Ratcliffe, 1999).

3.6.1 Characterizing Issues by Situational Features

Analysis of issues revealed that the majority of news articles feature four major situational features: (a) type of organism, (b) level of organization, (c) use of genetic technology, and (d) type of pathology. By parsing these features into their sub-features we found that many articles focused on an anthropocentric story describing the use of genetic technologies at the biochemical and organismal levels to identify, alleviate, or cure a genetic disorder of a physiological nature. Together, situational features and their specific sub-features, comprise how we define issues in this study. It is possible that the particular issue we identified as occurring frequently within articles is most prevalent due to the completion of the Human Genome Project in 2003. This project successfully mapped the human genome and has since led to the discovery of over 1,800 genes associated with human diseases and disorders (National Human Genome Research Institute [NHGRI], 2011), and subsequently to the development of new genetic tests, hundreds of biotechnology-based products, and insights into mechanistic explanations for genetic phenomena. Such a surge in genetic technologies and information now available provides a likely explanation for the frequency of situational features in the news media

that discuss issues relating to human pathologies and genetic technologies at varying levels of organization (molecular, cellular, and organismal).

The issues and their defining features portrayed in news articles are important to identify because this can provide insight as to the kinds of content knowledge needed to reason about modern genetic phenomena. Content knowledge itself can be derived from many sources, whether it be knowledge gained through disciplinary study, exposure to media sources, or personal experiences such as being diagnosed with and researching a genetic disorder. Additionally, knowledge can also be gained through the evaluation of information presented within a particular issue - such as statistical probabilities of conceiving a child with a rare genetic trait. The ability to apply such knowledge to a specific issue and one's familiarity with subsequent situational features and sub-features may also contribute to the generalization and application of knowledge across a variety of issues.

As demonstrated by several studies, students often have difficulty reasoning about phenomena comprised of situational features that are unfamiliar to them (Bransford & Schwartz, 1999; Heredia et al., 2012; Lewis & Leach, 2000; Nehm & Ha, 2011; Shea, Duncan, & Stephenson, 2011). To address this issue, current issues in genetics can be used to support national initiatives for scientific literacy. Once prevalent issues are identified and characterized, they can be employed as illustrative examples within curriculum to teach core ideas in the domain and promote transfer of learning. For example, genetics texts and curriculum repeatedly draw on identical examples of genetic phenomena. Most genetics and biology textbooks discuss Gregor Mendel's experiments from the 1850's - 1860's with pea plants as a classic example used to illustrate genetic

inheritance. This example is foundational for explaining how genes are inherited from one generation to the next and teaching students how to predict inheritance patterns. Other extensively used examples include eye color in fruit flies, antibiotic resistance in bacteria, and cystic fibrosis in humans. These examples serve provide a robust foundation for genetics education. However, the repeated use of similar examples in teaching genetics is problematic because this practice limits students' ability to transfer their learning to other, sometimes unfamiliar, issues (Heredia, et al., 2012; Nehm & Ha, 2011).

Identifying genetic phenomena as they are currently portrayed in the media and characterizing the issues in which they are cast may lead to the revitalization of examples used for teaching and learning modern genetics - especially in conjunction with classic examples - and may strengthen students' regard for lifelong engagement with science. Studies demonstrate that the use of current events in science, especially scientific phenomena portrayed in the media, increase students' engagement with curriculum, motivation to learn, and general interest in science as it applies to their daily lives (Lenz & Willcox, 2012; Mistler-Jackson & Songer, 2000; Mysliwiec, Shibley, & Dunbar, 2003). In addition, exposure to many examples that embody various features and sub-features of issues may lead to the improvement in transfer of learning and application of knowledge to novel problems.

3.6.2 Knowledge Analysis and Findings

Identifying and characterizing situational features was only one aspect of our analysis. We also wanted to determine what knowledge is likely necessary to understand phenomena comprised of these features. Our theoretical framework in part draws on the knowledge requirements hypothesized by a genetics learning progression (Duncan,

Rogat, & Yarden, 2009). The learning progression is based on educational research on student thinking and learning in genetics as well as national science standards, and proposes a learning trajectory spanning three levels of sophistication across eight big ideas. However, it appears from our analysis of news articles that the knowledge implicated in the learning progression occasionally falls short of what is anticipated to understand about ideas in the news articles we analyzed. For example, from our analysis of the big ideas indicated in the news articles, idea D - the concept that all cells have the same genes, but express genes differently depending on cell type and function, idea E - how genetic information is passed from parent to offspring, and idea F - how patterns of trait expression are correlated with gene expression and the probabilities with which these patterns are likely to occur, were only indicated at the most basic level of knowledge (i.e., understanding these concepts at the trait level without requiring explanation of underlying mechanisms). Studies exploring secondary school students' reasoning about genetic phenomena suggest that students have difficulty explaining mechanisms for genetic phenomena (Duncan & Reiser, 2007; Marbach-Ad & Stavy, 2000; Venville & Treagust, 1998). Thus, the learning progression suggests that knowledge supporting underlying mechanisms are crucial for reasoning about genetic phenomena (Duncan, Rogat, & Yarden, 2009). It may be the case that such knowledge is necessary to explain how genetic phenomena work; however, our analysis suggests that such knowledge may not be necessary for understanding genetics phenomena as they are presented in news articles and possibly in other scenarios commonly encountered in daily life.

Confounding this notion of over-specification is the finding that some big ideas - idea G in particular - exceeded the learning progression's hypothesized requirements in

terms of knowledge sophistication. Articles that invoked idea G often did so at a greater level of sophistication not anticipated by the learning progression. These articles often discussed phenomena about to genetic relatedness of individuals within and across species and the notion that genes from one organism can substitute for genes in another organism to demonstrate the functionality of the gene in each organism. This complex process is identified in most articles that indicate idea G to explain the phenomenon presented in the story, and exceeds what is expected for idea G in the learning progression. This suggests that curricular interventions may not be sufficiently detailed in some areas to support reasoning about current phenomena in genetics, thus potentially limiting individuals' ability to understand why or how phenomena exist.

In addition, the learning progression emphasizes all eight big ideas equally. Our analysis suggests that some big ideas - A, B, E, and G in particular - appear more frequently in news articles than the remaining four big ideas. Equal emphasis on all eight big ideas may result in inefficient curricular interventions where time is spent teaching some concepts that are less relevant for understanding genetic phenomena. For example, in a study examining middle school students' reasoning about genetic phenomena, Freidenreich, Duncan, and Shea (2011) demonstrated that learning the process of meiosis - how genes are passed from parent to offspring through sperm and egg - is not necessarily essential for predicting the outcome of genetic inheritance patterns. This begs the question if genetics curriculum should be reconsidered or reprioritized in order to meet the demands of mainstream science issues. However, we acknowledge that only considering phenomena presented in news articles is not sufficient for preparing students engagement with science. There are many facets to scientific literacy that need to be

taken into consideration (e.g., practices, domain-specific knowledge, and cross-cutting concepts (NRC, 2012)).

Identifying the prevalent problems presented in social media is one method for identifying the science issues individuals are likely to encounter, and has implications for deciding what we should teach inK-12 science classrooms. This analysis suggests that identifying and describing issues based on situational features is essential for understanding what knowledge will be useful as individuals are challenged to reason about such issues. Understanding the phenomena portrayed in the media is only one aspect among many that requires consideration when developing curricular interventions that support the development of scientific literacy. However, very few studies examine the phenomena individuals are likely to encounter during their daily lives, which is important for understanding civic engagement with science. We envision that the findings from this study may support the refinement of genetics curriculum that takes into account not only the phenomena individuals are likely to encounter, but also the level of knowledge sophistication required to understand and reason about such phenomena. In future studies we plan to explore individuals' knowledge use while reasoning about situational features identified in this study in order to test our theoretical model.

3.7 Implications

Two major implications stem from this work. First, from a science education perspective, findings from this study demonstrate that genetics news articles present domain-specific ideas that in some instances exceed the expectations of current curricular interventions. This is not entirely unexpected since technical knowledge of genetics increases at an astounding rate, but exceeding curricular expectations is problematic in

terms of preparing students for civic engagement with genetics issues they may encounter in their daily lives. It must be acknowledged that this study specifically analyzed news articles that only spanned the years 2010 and 2011. It is possible that some years may produce articles emphasizing specific topics and knowledge criteria, which may cause shifts in news coverage and place emphasis on aspects of content knowledge that differ from year to year. However, in this study, it appears that science writers (i.e., journalists) treat scientific discoveries and technological advances as an arena for complex descriptions of genetics phenomena that individuals may not be prepared to deeply understand. Understanding science news articles to their fullest capacity is not generally the prime initiative of the lay public (Feinstein, 2011). Many individuals read for what they find useful instead of attempting to learn all they can about a domain. Yet, brief encounters with complex phenomena presented in news articles may lead to superficial understandings of the science underlying these topics and generate alternative conceptions about the domain.

Second, from the perspective of science communication, the news articles in this study feature complex and rich descriptions of current events in genetics that can challenge and motivate public thinking. Nisbet and Scheufele (2009) argue that science communication efforts with the public should attempt to generate space for dialog rather than point to public knowledge deficits as a primary focus. Findings from this study demonstrate that news articles generally meet and sometimes exceed the expectations of current genetics education initiatives. Bridging the gap between what science educators know about how people learn and science communicators desire to engage the public in meaningful scientific discussions is critical for the development, support, and refinement

of science literacy. Not only will a collaboration between science education and science communication initiatives serve to effectively support public understanding of science, but the methodologies of these two domains can deeply inform one another about how individuals consider complex topics as those in genetics. Expanding data collection to include additional sources such as Internet sites, TV programs, or science magazines, may provide a broader survey of genetics issues and corresponding knowledge requirements and may also act as a bridge to for science educators and science communicators to learn how their disciplines inform one another.

Chapter 4:

Exploring the use of knowledge representations for reasoning about an authentic genetics phenomenon

Abstract

Supporting the development of students' scientific literacy is a central goal of science education initiatives. However, public understanding of science limited particularly in domains that advance rapidly, like genetics. This raises questions about the public's ability to participate knowledgeably in socio-scientific debates. We present our findings from a comparative study between undergraduate science majors, doctoral students in biological science programs, doctoral students in philosophy programs, and certified genetic counselors. We assessed participants' content knowledge of genetics using a multiple choice assessment, and conducted a semi-structured interview with each participant composed of a reasoning task about the genetics of obesity in humans. We assessed participant dialogue for genetic content knowledge and quality of reasoning about the phenomenon. Overall, we found that science doctoral students and genetic counselors drew on sophisticated knowledge representations to develop an integrated reasoning strategy about the task. Philosophy doctoral students nearly matched science graduate students and counselors on the content knowledge assessment, but had difficulty describing the genetics underlying the task. Despite this, one third of the philosophy students used an integrated reasoning approach during the interview suggesting that well developed reasoning skills may compensate for limited content knowledge. The undergraduate students had difficulty with both the knowledge assessment and interview task and could not integrate the information provided in the task to support their explanations. This work provides insights as to the conceptual obstacles and leverages involved in complex reasoning in the domain of genetics.

4.1 Introduction

Supporting the development of students' scientific literacy is a central goal of science education initiatives (AAAS, 2011; NRC, 2011). Our current view of knowledge and reasoning skills required for scientific literacy stems from science education standards that are based on experts' (in science and science education) notions of what is required to understand science (AAAS, 2011; NRC, 2011). This top-down approach for guiding the development of science literacy draws on numerous theoretical and empirical studies of how children learn science and experts' recommendations for what students should know about science (Anderson & Helms, 2001; Feinstein, Allen, & Jenkins, 2013; Weible, Sabatier, & Lubell, 2004). However, many studies demonstrate that students, and adults, have difficulty applying what they learn in the science classroom to reason about authentic science phenomena they encounter in their daily lives (Feinstein, 2009 & 2011; Feinstein, Allen, & Jenkins, 2013; Hofstein & Rosenfeld, 1996; Irwin & Wynne, 1996; Resnick, 1987; Thomm & Bromme, 2012). Reasoning, in this study, refers to an individual's ability to apply coherent and relevant knowledge representations when constructing and supporting an explanation of a phenomenon. The limited ability to transfer and apply science knowledge effectively to novel situations is problematic since civic engagement with science is rapidly increasing (e.g., the recent rise in marketing of direct-to-consumer genetics tests). We, and others, argue that the ability to apply science knowledge to reason about a variety of real-world phenomena embodies what it means to be scientifically literate (Feinstein, 2011; Hurd, 1998; Roberts, 2007).

The challenge of characterizing the knowledge needed to reason about socio-scientific issues is particularly acute for domains that both advance rapidly and impact

the public realm. The field of genetics is a compelling example as it is advancing at an astonishing rate, especially in terms of technological developments (e.g., gene therapy, genetic testing, cloning, etc). However, public understanding of these advances is limited (Condit, 2010). This raises questions about the public's ability to participate knowledgeably in socio-scientific debates (e.g., in 2012, Californians considered Proposition 37 calling for all genetically modified foods to be labeled), and to provide informed consent for a variety of novel procedures (e.g., genetic screens and stem cell research). Thus, the purpose of this study is to determine what knowledge representations are actually used by individuals with varying genetic content knowledge and reasoning ability to generate and support explanations of an authentic genetics phenomenon. We included participants with varying levels of genetics content knowledge since effective reasoning may not rest solely on expertise in the domain (Irwin & Wynne, 1996). We also included participants with varying reasoning ability to determine if knowledge of argument construction affects how individuals consider evidence within a reasoning task. Towards this end, we investigated the following research questions:

1. What knowledge representations do participants use to reason about an authentic genetics phenomenon?
2. How does use of knowledge representations to support reasoning differ between groups of participants with varying genetics expertise and reasoning ability?

4.2 Literature Review

There are several definitions of scientific literacy, many of which include notions of knowledge in use. Paul Hurd initially popularized the term scientific literacy in 1958 and later provided his definition as "a civic competency required for rational thinking

about science in relation to personal, social, political, economic problems, and issues that one is likely to meet throughout life" (Hurd, 1998, p. 410). As the notion of scientific literacy developed, Roberts (2007) contributed two broad perspectives on its definition, that he termed Vision I and Vision II. Vision I focused on what individuals need to know, or do, in order to be scientifically literate, such as the standards and perspectives outlined by education reform initiatives, such as *Project 2061* (AAAS, 2001). Vision II focuses on what science literacy looks like in action; that is, how scientific knowledge is used to reason about phenomena encountered in daily life. These descriptions of scientific literacy hold in common the need for scientific knowledge and use of such knowledge to reason about authentic scientific phenomena.

Literacy in the domain of genetics is less clearly defined. However, three components are commonly discussed, and therefore serve to define genetic literacy in this study. The first two components are supported by research in genetics education: (a) content knowledge of genetics (Duncan & Reiser, 2007; Bowling et al. 2008; Marbach-Ad, 2001; Venville, Gribble, and Donovan, 2005) and (b) the use of genetic content knowledge to develop and evaluate arguments (Bates, 2005; Jiménez-Aleixandre, Rodriguez & Duschl, 2000; Kerr, Cunningham-Burley, & Amos, 1998; Sadler & Donnelly, 2006; Zohar & Nemet, 2002). We also include a third component that has not previously been considered as part of genetic literacy: (c) individuals' ability to use both content knowledge and argumentation across different issues (Ceci & Ruiz, 1993; Chi, Feltovich, & Glaser, 1981; diSessa, 1988; Schwartz, Bransford, & Sears, 2005). While this component is not unique to genetics (all fields experience similar affects) there is very little research about the how situational features of an issue can influence reasoning

about genetics phenomena. This study specifically explores how individuals use their genetic content knowledge to reason about a genetic phenomenon comprised of authentic situational features. In the following sections we describe the three components of genetic literacy in more detail.

4.2.1 Content Knowledge of Genetics

One component of genetic literacy foregrounded in this study is the use of content knowledge to reason about an authentic phenomenon. Stewart, Cartier, and Passmore (2005) identified three major models of genetics knowledge that they argue support genetics literacy. They include: (a) the genetic (or inheritance) model, that describes the pattern of inheritance between parents and offspring, (b) the meiotic model, that describes the passage of genes from parent to offspring through sperm and egg, and (c) the molecular model that describes how genes are translated into proteins that bring about physical traits. Stewart et al. (2005) argue that to be considered genetically literate, individuals must understand the models themselves as well as how they are connected to one another, the latter being most challenging for individuals since connecting models requires knowledge of the mechanisms underlying each model (van Mil, Boerwinkel, & Waarlo, 2011). What follows is an examination of the three models that constitute knowledge of genetics and the difficulties individuals encounter when reasoning about them.

4.2.1.1 Understanding the inheritance model.

Understanding the inheritance model entails knowing that parents contribute half of their genetic material to their offspring. At an organismal level, inheritance refers to the passage of observable traits from parent to offspring. At a molecular level, inheritance

refers to the genes and chromosomes that are passed from parent to offspring and that bring about observable traits. Several studies suggest that knowledge of inheritance (i.e., heredity) is the most common concept the public understands and refers to when asked to discuss genetics. However, lay individuals frequently consider heredity at a superficial level, not at the level of genes or their products (Condit, 2010). For example, lay individuals find it difficult to reason about recessive genetic disorders and how they are passed from parent to offspring (i.e., how can a child with normal parents have a genetic disorder?). Lay people tend to hold alternative conceptions of genetic inheritance that side step notions of how genes are physically passed from parent to offspring, and draw the conclusion that genetic disorders can 'skip' generations (Henderson & Maguire, 2000). Considering this perspective at the observable trait level, the notion of 'skipping' is misleading, because at the level of the gene there is no skipping. A copy of each gene is passed from both parents to each offspring through sperm and egg. Lay individuals are often unaware that parents may carry a recessive version of a gene, thus carriers appear unaffected yet are able to pass that recessive version of the gene on to their offspring (Henderson & Maguire, 2000). This suggests that individuals hold accurate notions of kinship, but lack mechanistic explanations of inheritance at the molecular level. This is problematic if individuals with a recessive genetic disorder believe their children will not inherit that disorder because of this 'skipping' effect or that they are themselves incapable of passing the disorder to their offspring.

4.2.1.2 Understanding the meiotic model.

Understanding the meiotic model entails knowing that genes are passed from parent to offspring through sperm and egg, and that meiosis is the mechanistic process

underlying this phenomenon that results in each sex cell containing half of a parents' genetic information. Although individuals tend to hold accurate notions of parent-child relatedness, very few hold accurate understandings of meiosis and its products. Many lay individuals believe that a child can receive more than half of their genetic information from one parent versus another (Clough & Wood-Robinson, 1985), particularly if physical similarities are shared among dyads of the same gender. For example, in a large study (n = 457) conducted to assess individuals' knowledge about the heritability of cancer, de Vries, Mesters, van de Staag, and Honing (2005) found that 93% of participants believed that if a son looks like his father, he is more likely to inherit cancer if his father becomes diagnosed. This is problematic since individuals may wrongly suspect that they are unlikely to inherit cancer, or other genetic disorders, from their parents or extended family if they are of different genders. For example, de Vries et al. (2005) found that men are less likely than women to consider themselves at risk for breast cancer (a disease typically portrayed as one women inherit from their maternal relatives). Therefore men are less likely to seek care and treatment for diseases like breast cancer if they do not believe they are susceptible.

4.2.1.3 Understanding the molecular model.

Understanding the molecular model entails knowing the mechanisms by which genes determine traits. This model is especially useful for generating mechanistic explanations for genetic phenomena that explain how genes code for proteins and how proteins bring about traits. However, individuals often lack frameworks for understanding such molecular mechanisms at multiple organizational levels (van Mil, Boerwinkel, & Waarlo, 2011). For example, Marbach-Ad and Stavy (2000) present a view of genetics as

being composed of three main organizational levels: macroscopic (organismal), microscopic (cellular), and submicroscopic (molecular) levels, for which students must generate explanations that connect the levels. Marbach-Ad and Stavy (2000) found that high school students and pre-service biology teachers had difficulty generating molecular explanations for genetic phenomena that connect all three organizational levels. Although pre-service biology teachers most frequently generated explanations that exemplified connections between the three levels, many still had difficulty discussing submicroscopic agents, such as the three main types of RNA, as central to genetic phenomena.

Duncan & Reiser (2007) also found that high school students had difficulty generating complete mechanistic explanations and often left out important submicroscopic components such as proteins. Duncan & Reiser (2007) suggest that difficulties developing explanations at the molecular level arise because "students are not aware of the central roles proteins play in biological processes, [therefore] they do not presume that any biological phenomena, that has genetic origins, is likely mediated by proteins." (p. 952). Without knowledge about molecules, such as proteins, individuals struggle to productively reason about complex genetic phenomena (Duncan & Reiser, 2007).

4.2.2 Reasoning about Scientific Phenomena

The difficulty in problem solving about authentic phenomena is that it requires not only robust reasoning skills but also extensive domain-specific knowledge (Chi, Glaser, & Rees, 1981; Means & Voss, 1996; Sadler & Zeidler, 2005) since more than one aspect of the domain is typically emphasized. In large part, literacy in the sciences is determined by individuals' scientific reasoning abilities (Feinstein, 2011). ″Scientific

reasoning encompasses the reasoning and problem-solving skills involved in generating, testing and revising hypotheses or theories, and in the case of fully developed skills, reflecting on the process of knowledge acquisition and knowledge change that results from such inquiry activities" (Morris, Crocker, Masnick, & Zimmerman, 2012, p. 61). Effective scientific reasoning relies on two main components: (a) understanding of what is currently known in the domain along with the ability to attend to such information in order to draw inferences that support reasoning; and (b) the ability to develop hypotheses, evaluate data, generate arguments and rebuttals, devise testable theories, and design experiments (Morris et al., 2012). Thus, effective scientific reasoning depends on the coordination of evidence (i.e., domain-specific knowledge), and theory (i.e., scientific practices or strategies for problem solving). "Coordination implies reciprocal adjustment. Not only must evidence serve as the basis for evaluating and possibly revising theories, but also theories influence the direction and form of investigation" (Kuhn, Schauble, & Garcia-Mila, 1992, p. 321). Like informal reasoning, scientific reasoning requires the application of a give-and-take strategy between theoretical understandings and evidence.

The development of strategies depends in part on individuals' domain-specific knowledge since such knowledge guides attention to relevant features of a task (Morris et al., 2012; Schauble, 1996). Young children often attend to irrelevant features of reasoning tasks, this tendency appears to dissipate as they grow into adulthood. For example, in a study of fourth grade students reasoning about causal factors contributing to the speed of a model sail boat moving down a ramp, Kuhn, Schauble, and Garcia-Mila (1992) found that some students initially considered sail color as sail size causal factors for speed whereas they did not attend to water depth as relevant to speed. Over time, students

perceptions changed as they found features of the sail were irrelevant to speed, but still had difficulty acknowledging the role of water depth. Identifying what evidence is actually contributing to an outcome is difficult for children and adults (Chinn & Brewer, 1998; Kuhn, Schauble, & Garcia-Mila, 1992; Schauble, 1996). Often, individuals will develop theories that are not relevant to the reasoning task and will include data that confirms their theories, what Inhelder and Piaget (1958) term *false inclusion*. On the other hand, individuals may also exclude data if it does not align well with their notions of causation, regardless if the data is critical for explaining the phenomenon, termed *false exclusion*. Variations of these forms of inclusion and exclusion occur frequently as children and adults attempt to coordinate theory and evidence to support scientific reasoning (Kuhn, Schauble, & Garcia-Mila, 1992). The ability to validly include and exclude evidence in coordination with theory demonstrates sophistication of reasoning (Kuhn, 1993).

Schauble (1996) provided an example of reasoning differences between children (5th - 6th grade) and adults (not in college and with little scientific training) in her work. Participants were asked to generate evidence to support their theories about two complex tasks: reasoning about how water canals should be designed to optimize boat speed, and with the second task participants were asked to reason about the buoyant force on immersed objects of different mass and volume. During these sessions, adult participants demonstrated more systematic and comprehensive strategies in their experimentation, and used the VOTAT (vary one thing at a time) approach more so than the children, who would often manipulate several variables at once confounding their results. Adults were also better at evaluating the overall goals and outcomes of their experiments as they

reasoned about each task, whereas children often drew conclusions from a single experimental trial without testing their conclusions. Children and adults both generated equal numbers of trials over the sessions, and both groups improved their strategies from the first reasoning task to the second. However, a higher percentage of adults tested unique ideas in each trial while children tended to, unintentionally, duplicate their tests. Schauble suggests that adult participants may have a larger "library" of domain-specific knowledge from which to draw and develop understandings of causal mechanisms, that in turn supported strategy choices. The findings from this study suggest that both strategic and domain-specific knowledge play a role in the development of scientific reasoning, and appear to bootstrap each other.

The ability to weigh evidence and theory to support scientific reasoning about authentic phenomena determines one's scientific literacy. This form of literacy is dependent upon domain-specific knowledge, argumentation ability, and an understanding of factors that are relevant for explaining a causal mechanism. Individuals often struggle with these conceptions and require support to develop reasoning skills about scientific phenomena over time. Many phenomena individuals encounter in their daily lives require informal and scientific reasoning skills. This is especially true of genetics issues that are typically ill-structured and lack definitive outcomes, making deep reasoning difficult. For example, statistical probabilities are often used to convey information to patients about the likelihood they will develop a genetic disorder. These probabilities encompass many factors such as the patient's family history, age, gender, general health, and several environmental factors (e.g., level of exercise, diet and nutrition, exposure to pollutants, stress level, etc). Understanding how individuals apply domain-specific knowledge to

develop and support arguments about authentic phenomena and what components of knowledge matter in supporting their reasoning is important for shedding light on how scientific literacy develops.

4.2.3 Situational Features and Reasoning

The underlying assumption of schooling, that knowledge of core concepts generalizes to a variety of issues and that individuals can reason equally well about diverse topics (when the underlying scientific principles are the same) is proving problematic (Bransford & Schwartz, 1999; Shea, Duncan, & Stephenson, 2011). In this study, we define authentic issues by their situational features such as key players, technologies applied, pathology, etc. In prior work (Shea, Duncan, & Giannetti, 2013) we defined and characterized genetics issues presented in news articles. In that study, issues were characterized by the collective features that support a phenomena including content knowledge (e.g., specific aspects of genetics knowledge presented in the story) and language (e.g., what key words, phrases, and propositions are used to convey scientific concepts in the story). Our findings demonstrated that one type of issue in particular was featured most often: a story about a genetic phenomenon in which a genetic technology (e.g., gene therapy) was used to ameliorate a defective gene (e.g., biochemical level of organization) in an organism (e.g., humans) in order to reverse the symptoms (e.g., organismal level of organization) of a genetic disease (e.g., type of pathology). In the current study, we use these prevalent situational features as the basis for constructing the reasoning task.

The role of situational features in reasoning is important to examine because several studies demonstrate that such features can affect individual's ability to reason

(Heredia, Furtak, & Morrison, 2012; Nehm & Ha, 2011; Sadler & Fowler, 2006; Schwartz, Bransford, & Sears, 2005; Shea, Duncan, & Stepehnson, 2011). For example, Nehm and Ha (2011) explored how the situational features of assessment items about evolution affect student response patterns. Undergraduate students answered items that required the use of similar underlying evolution content knowledge yet differed in situational features, such as evolutionary gain or loss of a trait, type of organism, and whether the comparison was within or across species. They found that students were less likely to employ core ideas in natural selection to explain trait loss versus trait gain, and when making between species versus within species evolutionary comparisons.

Similarly, Sadler and Fowler (2006) suggest that the robustness of individuals' content knowledge, or lack thereof, may limit the extent to which they can use their knowledge to reason about a particular issue or across multiple issues. For example, individuals may reason using alternative conceptions about phenomena in which a genetic mutation is the underlying mechanism that generates a physical trait in organisms. Genetic mutations are often conceived of by the public as harmful events that lead to disease states, such as sickle cell anemia in humans (Kampourakis & Zogza, 2009). Therefore it is likely that individuals may consider the molecular mechanism for a disease state to include genetic mutations. They may be less likely to understand that "normal features", such as freckles in humans, arise from genetic mutations as well. Each of these issues requires similar knowledge of genetics (e.g., molecular mechanisms) yet we suspect that differences in whether the trait results in a disease state versus occurring as a normal function of the organism may influence reasoning strategies.

Taken together, these components of genetic literacy (content knowledge, reasoning, and composition of issues) serve to shape our understandings of how individuals reason about authentic genetics phenomena. This study specifically explores how content knowledge is used to reason about an authentic phenomenon comprised of commonly encountered situational features to determine what differences in reasoning exist across groups of participants with varying genetic expertise and argumentation ability. Findings from this study suggest that specific pieces of genetics content knowledge matter for individuals to develop robust reasoning frameworks.

4.3 Theoretical Framework

This study considers how individuals use their knowledge of genetics to reason about an authentic genetics phenomenon. Reasoning about underlying mechanisms can be quite difficult for students, especially when required to incorporate domain-specific knowledge (van Mil, Boerwinkel, & Waarlo, 2011). Mechanistic reasoning (i.e., describing the underlying casual mechanism of a phenomenon) is difficult for individuals for two main reasons: (a) it requires knowledge of the main organizational levels that support the phenomenon: macroscopic (organismal), microscopic (cellular), and submicroscopic (biochemical); and (b) it requires reasoning across the organizational levels in order to explain the causal mechanism (i.e., how genes relate to proteins, and how proteins bring about traits) (Marbach-Ad & Stavy, 2000). These two aspects of mechanistic reasoning are critical for supporting reasoning about genetics issues. If individuals lack understanding of key pieces of genetics knowledge that link organizational levels, such as proteins and their central role in genetic mechanisms, individuals will struggle to productively reason about complex genetic phenomena

(Duncan & Reiser, 2007). Mechanistic explanations in genetics are especially difficult for students who lack knowledge of molecular entities - proteins in particular (Duncan, 2007). Thus we focus on participants' ability to apply notions of molecular genetics when reasoning about the phenomenon presented in this study.

To determine how genetics content knowledge is used to support participants' reasoning, we draw on the work of Duncan (2007) who developed a cognitive model of generative reasoning in molecular genetics. The model describes how undergraduate students used genetics content knowledge to support their reasoning about genetics issues. The framework suggests that when reasoning about molecular genetics phenomena students begin by generating a generalized framework that captures their initial ideas about a reasoning task - termed a *solution frame.* A solution frame serves "to define in broad strokes potential solutions thereby establishing placeholders for knowledge of relevant domain-specific entities and processes" (Duncan, 2007, p. 285). Thus, a solution frame is not specific to genetics, or any particular domain, but instead provides a broad framework that students employed outline their explanation of the phenomenon in question.

Duncan's model postulates two main knowledge representations that serve to operationalize general solution frames into domain-specific explanations: *domain-specific heuristics* (hereafter referred to as heuristics) and *domain-specific explanatory schemas* (hereafter referred to as schemas). Heuristics serve to define the key *components* of a system (e.g., the notion that genes code for proteins or that proteins are central to genetic phenomena). Schemas on the other hand, serve to determine the *interactions* that can occur between key components of a system (e.g., how proteins interact with one another to send signals across a cell to cause a genetic phenomenon). If a solution frame

is the domain-general scaffolding shaping an individual's ideas about a phenomenon; heuristics and schemas are the individual's domain-specific understandings that serve to conceptualize an explanatory mechanism for that specific genetic phenomenon.

This study explores the kinds of knowledge representations (heuristics and schemas) participants use when reasoning about a genetics phenomenon. We drew on Duncan's model as it elucidates the specific knowledge representations individuals use as they reason about the phenomenon presented in a reasoning task. Participants in Duncan's work often elaborated their explanations by including declarative descriptions of science content knowledge - what Duncan terms *propositional knowledge* - and spatial, temporal, and causal representations used to support their explanations - what Duncan terms *mental models*. Our study follows Duncan's work in order to establish participants' knowledge use in the form of heuristics, schemas, propositional knowledge and mental models. The contribution of this work is the refinement of Duncan's model to characterize the detail with which participants provide explanations. Duncan (2007) examined basic knowledge use for developing explanations about the reasoning tasks. She was primarily concerned "with the bare essentials of domain-specific knowledge that are necessary and sufficient for reasoning in molecular genetics" (p. 311). Our work differs in that we were interested in determining how content knowledge application and reasoning differed across groups of participants. Thus, we included not only heuristics and schemas in our analysis, but also parsed the level of detail that was provided to support explanations (use of mental models and propositional knowledge). This method refines Duncan's original model and provides a finer grained approach for identifying how participants used knowledge representations to reason about a genetics phenomenon.

In addition, in this study we elaborate on the types of heuristics participants apply in their explanations. Duncan's model characterizes three heuristics that draw on canonical knowledge of molecular genetics: (a) genes code for proteins - the notion that genes are instructional in nature and code for physical entities, proteins, that bring about genetic phenomena, (b) proteins as central to a genetic phenomenon - the notion that proteins are the physical entities that bring about specific traits where damage to proteins can result in a genetic disorder, and (c) effects through interaction - the notion that physical interactions (protein-protein, protein-receptor, gene-protein, etc) elicit genetic phenomena. These three heuristics embody the molecular components necessary for developing robust explanations. However, other less specific heuristics are also productive for mediating genetics explanations. In this study, we identify additional heuristics that support participants' reasoning, but may not be considered canonical in nature. By identifying levels of sophistication for schemas and expanding the types of heuristics considered as productive for reasoning, we were able to closely examine how individuals with varying genetics expertise differ in terms of content knowledge application as they reasoned about a genetics phenomenon.

4.4 Methods

4.4.1 Study Context

Participants were predominantly undergraduate and graduate students recruited from a major research university in the North Eastern United States. Student participants included three distinct groups: (a) undergraduate science majors who completed eight credits of introductory biology coursework (lecture and laboratory) (n = 15), (b) ABD (all but dissertation) graduate students in genetics and other closely related doctoral science programs (n = 15), and (c) ABD graduate students in a philosophy doctoral program (n =

15). A fourth group of participants included certified genetic counselors (n = 15) from various hospitals across the United States (recruited via the National Society of Genetic Counselors website).

The four sample groups were specifically chosen to represent differing levels of expertise in terms of genetic content knowledge (undergraduate and science graduate students), argumentation and reasoning skills (philosophers), and knowledge of real-world socio-scientific genetics phenomena (genetic counselors). Undergraduate students were expected to have the least detailed expertise in reasoning skill since they had little formal training in scientific practices and had not taken coursework including argument development. Philosophy graduate students were expected to have well-developed reasoning skills, but little content knowledge of genetics (most had not received formal education in genetics since taking Biology in high school). Graduate students in genetics were expected to have moderate to high level understanding of genetics content knowledge and genetics issues depending on their specific training and coursework, but low to moderate level reasoning skills. Genetic counselors were expected to have moderate to high-level understanding of genetics - particularly of issue-specific knowledge since they are practitioners and are required to explain a variety of genetics concepts to their patients on a daily basis, but low to moderate level reasoning skills.

4.4.2 Instruments

We administered two instruments: (a) a content knowledge survey to determine participants' knowledge of genetics and (b) a semi-structured qualitative interview to explore how individuals use their knowledge of genetics to reason about an authentic genetics phenomenon (discussed below).

The content knowledge survey consisted of twenty multiple choice questions from previously validated and reliable genetics knowledge assessments such as items developed by AAAS *Project 2061* (AAAS, 2011), the Test of Basic Genetic Concepts (Sadler, 2003), the Genetics Concept Assessment (Smith, Wood, & Knight, 2008), and the Genetic Literacy Assessment Instrument (Bowling et al., 2008) (see Appendix A). Each participant completed the paper and pencil survey to assess their genetic content knowledge prior to participating in individual interviews. The survey provided a measure of participants' content knowledge in genetics specifically mapping onto the three models of genetics (Stewart, Cartier, & Passmore, 2005).

After participants completed the surveys, the first author conducted an hour-long interview with each participant that consisted of one multi-part reasoning task. The task required interviewees to consider an authentic and ill-defined phenomenon, to take a establish and support a position regarding the phenomenon, and provide an explanation of a causal mechanism underlying the phenomenon. The description of the genetic phenomenon was chosen based on prior research (Shea, Duncan, & Giannetti, 2013) that explored prevalent issues and corresponding situational features in *New York Times* articles featuring genetics phenomena. Thus, the interview task in the current study featured these situational features relevant to our previous findings (see Appendix B).

The reasoning task described the story of an obese man - Mr. Oswald - who took part in a genetics study and learned he had a mutation in the FTO gene (fat mass and obesity-associated gene), known to affect metabolic rate and appetite. Mr. Oswald believed his obesity was solely derived from his poor lifestyle choices (e.g., he frequently consumed fast food), but a researcher/s disagreed with his position and suggested his

FTO gene mutation played a significant role in his condition. The only information provided about the gene described in the scenario was that it was associated with changes in appetite and metabolism. The task also provided information about Mr. Oswald's family history of obesity across three generations and provided supplementary data about a twin study examining the interaction between smoking and obesity. The study was included to provide background information about the effects of environmental factors, such as smoking, on genetic disorders, such as obesity.

Participants were asked to establish an initial position – essentially, did they believe environment (e.g., diet and exercise) was the sole cause for Mr. Oswald's obesity, or that genetics (e.g., the mutant FTO gene) was the sole cause for Mr. Oswald's obesity, or that something different (e.g., a combination of the two factors). Subsequently, participants were asked about their understanding of: (a) the molecular mechanism underlying obesity, (b) patterns of inheritance of the gene, and (c) how genetic and environmental factors can contribute to such a condition. The interview was semi-structured in nature allowing for follow up questions on ideas initiated by participants (Brenner, 2006). Finally, participants were asked to reevaluate their initial position and state their final position after discussing all aspects of the interview.

4.4.3 Data Analysis

4.4.3.1 Survey analysis.

The knowledge survey served as an independent measure of content knowledge to determine if there were concepts participants understood in principle, but did not use in practice. Participants' answers to the multiple-choice questions were scored as correct or incorrect. Scores were averaged per group in order to draw comparisons between groups.

Findings from the survey analysis were used to identify any gaps or discrepancies in participants' knowledge use during the interview. For example, a participant may not invoke knowledge of proteins as central to genetic mechanisms during the interview task, but did recognize this notion as accurate in the knowledge survey. Participants may not include conceptions of proteins in the interview because they do not know much about protein function as related to the reasoning task or because they do not see it as relevant to invoke this idea in the case of obesity. We identified and recorded accurate responses to knowledge survey items for each participant. Questions relating to molecular genetics were compared to participant responses during the interview.

4.4.3.2 Interview analysis.

We first tracked individuals' initial and final positions (whether they considered the phenomenon to be genetically derived, environmentally derived, or a combination of the two) during the interview and determined if they changed their position from the beginning to the end of the interview. Although many participants did not change their position, they appeared to use different reasons to justify their initial and final positions. We used an inductive approach (Miles & Huberman, 1994) to parse out the various reasons participants cited as grounds for their initial and final positions.

We next identified four distinct segments of the interviews that provided salient opportunities for participants to demonstrate their reasons in supporting their initial and final positions. These segments included: (a) the initial position (participants were directly asked to construct a position after reading the interview task and were further prompted to provide support for their position), (b) responses to the molecular questions - participants were asked to provide a mechanistic explanation for the genetic phenomena

presented in the task, (c) responses to the nature and nurture questions - participants were asked to reflect on how genetic and environmental factors may contribute to a genetic phenomena, and (d) the final position- participants were asked to evaluate and possibly revise their initial position as they reflected on the interview as a whole. These four segments of the interview provided participants opportunities to explain in detail their understandings of the genetic phenomenon and provide support for their positions and thus were the primary focus of the analysis for characterizing reasoning differences across participants. We initially classified participants reasons as being about environmental factors (e.g. diet), genetic factors (mutations, genetic predisposition) or both.

We then grouped participants based on the kinds of reasons they used to support their positions: whether they used solely environmental reasons, solely genetic reasons, or a combination of both. The vast majority of participants used a combination of both environmental and genetic reasons to support their positions during all four segments of the interview; and, they did so in two main ways: (a) those that considered environmental and genetic factors to be intertwined and directly affecting the genetic phenomenon presented in the task (factors in *partnership*) and (b) those that considered environmental and genetic factors to be equally contributing but not directly related to one another (factors in *parallel*). For example, participants with notions of factors in partnership may say that environmental factors such as diet and exercise can contribute to gene expression patterns that ultimately lead to a disease state. Whereas, participants with notions of factors in parallel may say that environmental factors such as poor diet can lead to the onset of obesity, while genetic factors such as the mutated FTO gene can slow metabolic

function leading to weight gain. Of the participants who suggested that both environmental and genetic factors contributed to the phenomena presented in the interview task, we applied codes of *partnership* or *parallel* to each of the four major segments for reasoning in the interview. An inter-rater reliability of 90% was established between two independent raters for 40% of the data. Any disagreements were discussed and resolved.

To determine why participants differed in terms of reasoning (partnership versus parallel), we next looked to patterns of genetic content knowledge use across all participants. We decided to focus on difference in knowledge use regarding the molecular questions (one of the four major segments of reasoning). Responses to this set of questions demonstrated distinct differences between participants in terms of knowledge use and mechanistic reasoning more so than in any other interview segment.

For the analysis of knowledge use, we drew on the cognitive model of reasoning about genetic phenomena described above (Duncan, 2007). We used the methods and coding scheme described by Duncan (2007) to identify and code domain-specific explanatory schemas. In some instances, heuristics and schema were added to the coding scheme presented by Duncan (2007) since the task presented in this study emphasized aspects of molecular genetics not captured in Duncan's work. A complete description of heuristics and schema are detailed in the results section. An inter-rater reliability of 98% was established between two independent raters. Any disagreements were discussed and resolved. The molecular explanations participants developed differed in terms of sophistication. We developed a coding scheme to capture these differences. The coding scheme consisted of three levels with increasing sophistication: (a) level 1 - participant

has some notions of a genetic mechanism but does not identify mediating factors, (b) level 2 - participant details a genetic mechanism and identifies a mediating factor (e.g., a protein, hormone, or complex structure), (c) level 3 - participant details a genetic mechanism, identifies a mediating factor, and provides a detailed example of the role of the mediating factor (e.g., protein as a signal receptor). An inter-rater reliability of 91% was established between two independent raters for 40% of the data. Any disagreements were discussed and resolved.

4.5 Results

4.5.1 Tracking Participants' Positions

We surveyed each participant's initial and final positions to determine if they changed their minds from the beginning to the end of the interview (Table 4.1). Of the four participant groups, undergraduate participants were most likely to change their mind from the beginning to the end of the interview.

Table 4.1.
Percentage of participants who changed their positions during the interview

Participant Groups	**Change (# participants)**
Genetic Counselors	1
Grad Science	2
Grad Philosophy	4
Undergraduate	7

We also assessed whether participants considered environmental factors, genetic factors, or some combination of factors as causing obesity (Table 4.2). Participants rarely

provided justifications for their positions until later in the body of the interview. At the initial and final segments, participants were simply asked to state whether they were leaning towards one side or the other. The vast majority of participants (52 initially (91%), and 53 finally (93%)) suggested that both genetic and environmental factors contribute to the condition, either equally or with greater emphasis on environmental or genetic factors. Of the few participants that did not fall into this category, very few participants - all of which were philosophy graduate students - stated that they required more information to draw a satisfactory conclusion. One participant - an undergraduate student - initially believed that environmental factors were the sole contributing factor to obesity in the task, but later changed his position to both genetic and environmental factors contributing to the phenomenon. Analysis of participants' positions suggested that even though most participants considered both environmental and genetic factors as relevant to the phenomenon, they did so for different reasons. Thus, the remaining analysis focused exclusively on discerning differences in reasoning across those participants who suggested that both factors contribute to obesity either initially, finally, or in both segments of the interview (n = 57).

Table 4.2.
Participants' positions at the beginning and end of the interview

Position	Initial (# participants)	Final (# participants)
Both (with equal emphasis)	33	32
Both (with emphasis on environmental factors)	14	16
Both (with emphasis on genetic factors)	5	5
More Information Needed	4	4
Environmental factors only	1	0

4.5.2 Examining the 'Both' Response

We noticed that participants either considered environmental and genetic factors to be integrated with one another - what we term a *partnership model of reasoning* - or, they considered each set of factors as contributing to the disorder but not related to one another in any way - what we term a *parallel model of reasoning* (Figure 4.1). Of the 95% of participants that suggested that both environmental and genetic factors play a role in obesity for this task, 37% provided explanations indicative of the partnership model of reasoning. This method of reasoning is highly complex as it relies on a deep understanding of genetic content knowledge, molecular mechanisms, and the relationship between factors that contribute to a genetic phenomenon. For the purposes of this study, we consider such reasoning as evidence of expertise in the domain of genetics since employing the partnership model entails the coordination of evidence, theory, and domain-specific knowledge. The integration of multiple ideas about a domain must be compared and relationships between ideas must be conceived in order to employ the

partnership model of reasoning. This integration of knowledge is foundational to the development of expertise in a domain (Linn, 2000).

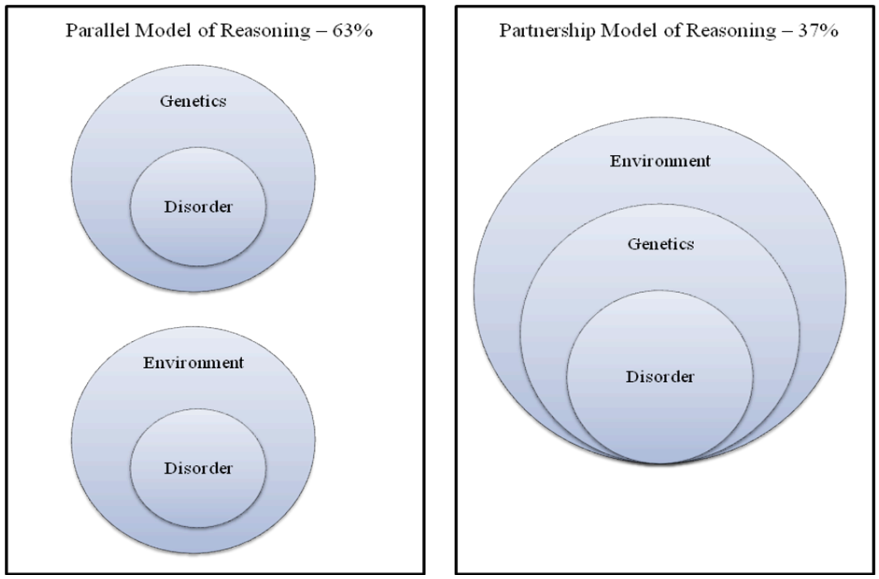


Figure 4.1. Models of parallel and partnership reasoning with corresponding distributions for participants using each model during the interview.

For example, in the following excerpt, Trisha, a genetic counselor, employs the partnership model of reasoning during the initial position segment of the interview:

Int	What do you think the doctors meant by "the percent likelihood of developing a genetic disorder is variable from person to person depending on environmental factors"?
Trisha	The analogy that I use if you have a gun and the genes are like the bullets in the gun and the environment is what pulls the trigger. So if you have the right environment to pull that trigger, you will develop obesity. If you don't have the right environment to pull the trigger - even if you have all the mutations - you may never pull that trigger because your environment is actually not supporting the development of the condition. The more we learn about epigenetics for instance, the more we start to realize that diet, environment, exercise actually changes methyl groups that turn on and turn off genes and change their expression. That's huge - it shows that the template is there, but its dependent on the environment.

Trisha views the environmental factors and genetic factors as partnered with one another in order to bring about an effect (i.e., obesity in this case). She offers the metaphor of the

bullets as genes and the environment as what "pulls the trigger". By this metaphor, and the Trisha's understanding, mutated genes may always be present within the DNA (i.e., "the template") of an organism, but may only produce an effect given certain environmental triggers. Trisha further supports this concept by drawing on her own prior knowledge of epigenetics - a relatively new branch of genetics research that explores how gene expression patterns are influenced by factors other than changes to the sequence of DNA itself. She states the external environment can physically change how genes are expressed by influencing factors (i.e., "methyl groups") that contribute to processes associated with gene expression. Trisha thus demonstrates her knowledge of how environmental and genetic factors are partnered to bring about an effect such as obesity.

The remaining 63% of participants stating both environmental and genetic factors contribute to obesity did so with equally detailed reasons, but in ways that neglected to demonstrate the relationship between factors. This parallel model of reasoning is exemplified in the following excerpt from the nature and nurture segment of the interview conducted with Nora, a science graduate student:

Int	So Mr. Oswald is obese, and he has two sons. One son obese and the other is not. Does that suggest anything about the mutation in terms of genetics and environment?
Nora	If its genetically influenced then one of them have the gene that makes you obese. Maybe one of them had a really awesome track coach in high school and really likes to run around a lot and it doesn’t matter what gene he has. They could have different inherited things, but they could also do different stuff.

In this example, Nora acknowledges that both genetic factors (having the mutated gene) and environmental factors (physical activity such as running - or lack thereof) can contribute to obesity. Nora considers these factors as equally contributing, but separate

from one another when she states: "They could have different inherited things, but they could also do different stuff". Unlike Trisha's use of partnership reasoning, Nora demonstrates a parallel model of reasoning as she views factors as independent of one another. If Nora were to use a partnership model of reasoning in this case, she may have suggested that physical activity increase the expression of genes responsible for regulating appetite and metabolic functions thus leading to reduced body weight.

Other participants employing the parallel model of reasoning suggested similar ideas. For example, Nate - a philosophy graduate student, suggested that both diet and genetics can contribute to obesity in the following way:

Int	What about Mr. Oswald's children, why do you think that only one son is obese and the other is not?
Nate	It could be environmental, one of them eats healthy and the other one doesn't. It's also possible there is a genetic difference; maybe the FTO gene got passed on to one and not the other.

Like Nora, Nate does not consider the relationship between the environmental (in this case, diet) and genetic (inheritance of the mutated gene) factors in this case. To do so, Nate may have suggested that certain foods or ingredients in food may trigger the expression of genes to regulate appetite and metabolic functions. Other participants using the parallel model of reasoning also considered sleep duration, stress level, and medications as contributing environmental factors for obesity. However, in all cases these factors were considered independently from having the mutated FTO gene or having other genes that may influence the expression of the FTO gene. It is important to note that we consider the parallel model of reasoning to also be relatively sophisticated because participants are able to consider multiple factors as simultaneously contributing

to a complex genetic disorder. However, we consider this model as less robust than the partnership model because individuals only recognize relevant factors that explain a phenomenon but do not draw connections between factors to support their explanations. Thus, using the parallel model of reasoning limits explanatory power because participants do not demonstrate how factors may influence one another in causing a phenomenon to occur. Use of the parallel model may be a consequence of less sophisticated content knowledge and mechanistic understandings needed to support integration of environmental and genetics factors. It is still unclear why these differences in reasoning exist.

4.5.3 Explaining Differences in Reasoning Strategy Use

One explanation for the difference in reasoning strategy may be variation in genetic content knowledge associated with training, expertise, and exposure to curriculum. For example, genetic counselors and graduate students in the sciences might be expected to employ the partnership model predominantly since these participants have completed at least Master's level course work in genetics. Genetic counselors must complete graduate level genetics course work as part of their degree and all of the graduate students completed a molecular genetics course as part of their doctoral program. Also, counselors discuss genetics with their patients on a daily basis and the graduate student group taught general biology laboratories to undergraduate science majors that included several weeks of genetics lessons.

Despite exposure to and experience with genetics phenomena, counselors and science graduate students did not exclusively use of the partnership model of reasoning (73% and 40% respectively) nor were these two groups the only participants to use

partnership model reasoning (Table 4.3). About a third of the philosophy students (33%) were also able to develop explanations that employed the partnership model of reasoning. The undergraduate students, however, exclusively applied the parallel model of reasoning. We triangulated this finding by referring to participants knowledge survey scores for all twenty items (overall) and specifically for the eight molecular genetics items incorporated in the survey. We found that participants using the partnership model of reasoning (n=21) scored very high on the knowledge survey overall (≥93% correct responses) and this score only slightly increased when assessing the molecular questions alone (≥94% correct responses) (Table 4.3). We also found that participants using the parallel model of reasoning (n = 36), scored lower on the same sets of items, with the undergraduate students scoring significantly lower overall (74% correct responses) and for molecular items (60% correct responses). This suggests that content knowledge, particularly about molecular genetics, influences reasoning ability.

Table 4.3.
Participants' use of partnership or parallel model reasoning and responses to content knowledge survey

		Certified Genetic Counselors	Science Graduate Students	Philosophy Graduate Students	Undergraduate Science Students
Participants with "both" reasoning (n = 57)	% Partnership Model Use	73%	40%	33%	0%
	% Parallel Model Use	27%	60%	67%	100%
Participants using partnership model (n = 21)	% Correct All Items	97%	97%	93%	-----
	% Correct Molecular Items	99%	99%	94%	-----
Participants using parallel model (n = 36)	% Correct All Items	94%	94%	91%	74%
	% Correct Molecular Items	91%	93%	88%	60%

Content knowledge may vary across individuals in part due to personal interest in the topic, completed coursework, familiarity with the topic due to having a genetic disorder themselves or knowing someone (e.g., such as a sibling or friend) who has a genetic disorder, or some combination of the above factors. In particular, it was interesting that the philosophy graduate students knew more about genetics and specifically molecular genetics than the undergraduate science majors based on the knowledge survey results. This may be explained by personal interest in the sciences despite not completing coursework in genetics after graduating high school. We next

examined difference in content knowledge use across individual participants during the interview to determine if specific concepts mattered for applying a partnership or parallel reasoning model to the interview task.

4.5.4 Content Knowledge Differences

To determine differences in genetic content knowledge use across participants, we specifically focused on the molecular segment of the interview since it provided the most salient opportunities for analyzing use of knowledge representations by participants and participants were prompted to explain their ideas about mechanisms. The other three segments of the interview elicited more general explanations relating to genetic and environmental factors without requiring specific detail as to the underlying mechanism of the phenomenon. Thus we suspected that responses to the molecular segment would provide the most insight in terms of knowledge differences while reasoning about the phenomenon.

In the molecular segment, participants were first asked to define terms such as gene, DNA, protein, and genome. Participants were then asked how and if these terms were related Participants were reminded that the mutated FTO was thought to cause changes in appetite and metabolism and were asked to explain how they believed a mutation in the FTO gene could result in obesity. Participants typically began describing mechanisms by offering general statements. In these cases, participants were promoted with questions such as "do proteins have anything to do with it?" or "how exactly do you think the mechanism takes place inside the cells?" in order to stimulate deeper thinking about the molecular aspects of the task. We completed a two-part analysis of their

responses in order to identify the heuristics, schema, and sophistication of the schema participants used in their development of mechanistic explanations (Duncan, 2007).

4.5.4.1 Use of heuristics.

"Domain-specific heuristics are principle-like knowledge pieces that are applicable to a wide variety of phenomena in the domain of molecular genetics" (Duncan, 2007, p. 291). These heuristics exemplify core concepts in the domain and serve to constrain and guide explanations using domain-appropriate entities such as genes, proteins, and cells. Duncan (2007) identified three heuristics in her work: (a) genes code for proteins, (b) proteins as central to a genetic phenomenon, and (c) effects through interaction - that were also applied to this work (Table 4.4). These three heuristics rely on canonical understandings of molecular genetics and thus we term them *central heuristics* (see Table 4.4). For example, in the following excerpt, Dean, a science graduate student, demonstrates his knowledge of genetics and invokes all three central heuristics in his explanations:

Int	What does that mean to have a mutated version of a gene?
Dean	Genes are the actual units of information within DNA, so a single gene encodes an amino acid sequence of a protein. When there's a change in the DNA sequence in that gene, that might cause a change in the amino acid sequence of the protein, which would cause the protein to function differently in some way leading to a potential genetic disorder - that's the mutated version of the gene.
Int	In the article they say that the mutation was expressed in the brain cells. How could a mutation affect how a brain cell works?
Dean	Brain cells being neurons are involved in sending and receiving information. So a lot of this is going to involve channels in the cell membrane that have to either let something in or out or attach to something and then open to somehow open to let a signal go back and forth. So if there's any change in the DNA that causes an amino acid switch in that region that attaches to a neurotransmitter and doesn't allow

> it to accept a certain neurotransmitter that's going to change the pattern of signals the cell can send and receive and when.

In this example, Dean identifies genes as coding for proteins when he states that "Genes are the actual units of information within DNA, so a single gene encodes an amino acid sequence of a protein". In this example, Dean articulates genes as informational in nature and that they code for physical subunits - amino acids - that make up proteins. Dean also demonstrates his knowledge of the heuristic proteins as central to a genetic phenomenon when he states that changes in the amino acid sequence " would cause the protein to function differently in some way leading to a potential genetic disorder". In this case, Dean recognizes that proteins have specific functions in cells and when these functions are disrupted by mutations, genetic disorders can result. Finally, Dean demonstrates his knowledge of the heuristic effects through interaction when he responds to the question about how a mutation affects the function of a brain cell. Dean begins to describe a mechanism for neuron functioning in terms of signals being relayed to cause specific functions inside the cell. Although Dean is not explicit in terms of a precise function for proteins - he mentions channels and signaling, but not in conjunction with proteins - he does state that "if there's any change in the DNA that causes an amino acid switch in that region that attaches to a neurotransmitter and doesn't allow it to accept a certain neurotransmitter, that's going to change the pattern of signals the cell can send and receive". With this statement, Dean is implying that proteins that operate in and on the surface of brain cells require specific structures to interact with the cell and allow the passage of signals in and out of the cell. Specifically, he implies that a protein can "accept a certain neurotransmitter". This interaction causes a direct effect - the specific pattern of signals the cell can send and receive.

Table 4.4.
Description of central and transitional heuristics used by participants during the interview

	Heuristic	**Definition**
Central Heuristics (Duncan, 2007)	Genes code for proteins	Genes provide instructions for the structural components that make proteins
	Proteins as central	Proteins are the mediating factor in all genetic phenomena
	Effects through interaction	Proteins interact with each other or with chemical signals to create an effect
Transitional Heuristics	Genes as information	Genes are informational in nature with no distinct outcome noted
	Genes as active	Genes cause events to occur or control how events occur
	Genes determine traits	Genes mediate phenotype with no mention of proteins
	Proteins as structural	Proteins are considered to have only a structural role in the cell

In addition to these three central heuristics, we also observed participants using less sophisticated heuristics in their definitions and explanations. We term these *transitional heuristics* because while not inaccurate, they are incomplete (Table 4.4). We identified four transitional heuristics in our data corpus: (d) genes as information - the notion that genes are informational - they provide instructions - but it is not clear how that information in used by the cell, (e) genes as active - the notion that genes cause or control

events at the level of the cell or body, but no mechanism is offered to explain such control (e.g., proteins), (f) genes determine traits - the notion that genes determine the phenotype of an organism, but no mention is made of proteins that bring about traits, and (g) proteins as structural - the notion that the sole function of proteins is to provide physical structure to the cells and the organism without acknowledging that proteins also serve other important functions such signaling, transport, catalysis, etc. For example, in the following excerpt, Nate, a philosophy graduate student, employs three heuristics (genes as active, genes determine traits, and proteins as structural) to define genetic terms:

Int	What is DNA?
Nate	It's an encoding of our genes, so it's something that is in our cells. It gets copied and that influences how are cells are produced. It produces various phenotypes.
Int	What are genes?
Nate	My assumption is that DNA encodes the genes and genes are physical. When I think about it one way I know DNA and genes are distinct but I don't know the distinction.
Int	What is a protein?
Nate	The DNA gets carried from one cell to another and that produces genetics somehow. Proteins are a bunch of amino acids and we need them to build cells. They are the building blocks of the cells.

In this example, Nate uses heuristics that are less sophisticated than those Dean employed. Nate's understandings are transitional in nature. Nate uses the genes as active heuristic when he states that DNA is "an encoding of our genes" and "influences how cells are produced". This idea is not implausible, DNA makes up genes that code for proteins and proteins bring about traits such as cell differentiation (i.e., how cells are

produced). Where his notion falls short is that his idea does not include the constituent proteins as a mediator for this process and he views DNA and genes as synonymous. In fact, DNA are the building blocks that when arranged in particular sequences, make up genes. Along the same lines, Nate invokes the genes determine traits heuristic when he takes the genes as active heuristic one step further by stating that DNA (and genes) "produces various phenotypes". Again, this is not entirely incorrect since genes are information used to generate proteins that bring about traits (i.e., phenotype). However, Nate circumvents the mechanism involved. Finally, Nate understands that proteins are important, but only as structural entities "Proteins are a bunch of amino acids and we need them to build cells. They are the building blocks of the cells". Here, Nate suggests that proteins contribute solely in a structural to physically build the cells. This is not incorrect as many proteins serve structural functions. However, proteins in general have a variety of functions critical for survival such as increasing reaction rates, acting as signaling mechanisms, or degrading waste materials in cells, etc.

Ultimately, we were interested in determining how use of genetic content knowledge maps onto to the use of the partnership and parallel models of reasoning. Use of specific heuristics was established for participants based on their responses to the molecular section of the interview. Participants varied in terms of the types and groupings of heuristics they used as they formulated their responses. Some used only a single heuristic such as genes code for proteins, and others used combinations of heuristics in their responses, such as genes code for proteins and effects through interaction. Most participants drew on either all three central heuristics or a combination of central and transitional heuristics in their explanations. In order to demonstrate how participants

coupled heuristics in their explanations, we grouped their use in Figure 4.2. It is important to note that these groupings are mutually exclusive and represent individual participants' use of specific heuristics. Values representing heuristic use are parsed into those participants who employed the partnership model of reasoning (dark grey bars) and those who employed the parallel model of reasoning (light grey bars). For those participants applying the partnership model, most used central and transitional heuristics (36%) or all three central heuristics (36%) frequently in their descriptions and explanations of the phenomenon. The central heuristics in the "central and transitional heuristics" category were predominantly genes code for proteins and proteins as central. Participants employing the parallel model of reasoning predominantly used central and transitional heuristics (54%) in their descriptions and explanations with few participants using central heuristics exclusively. This suggests that understanding that genes code for proteins and proteins are central to genetic phenomenon are critical for employing an integrated reasoning strategy.

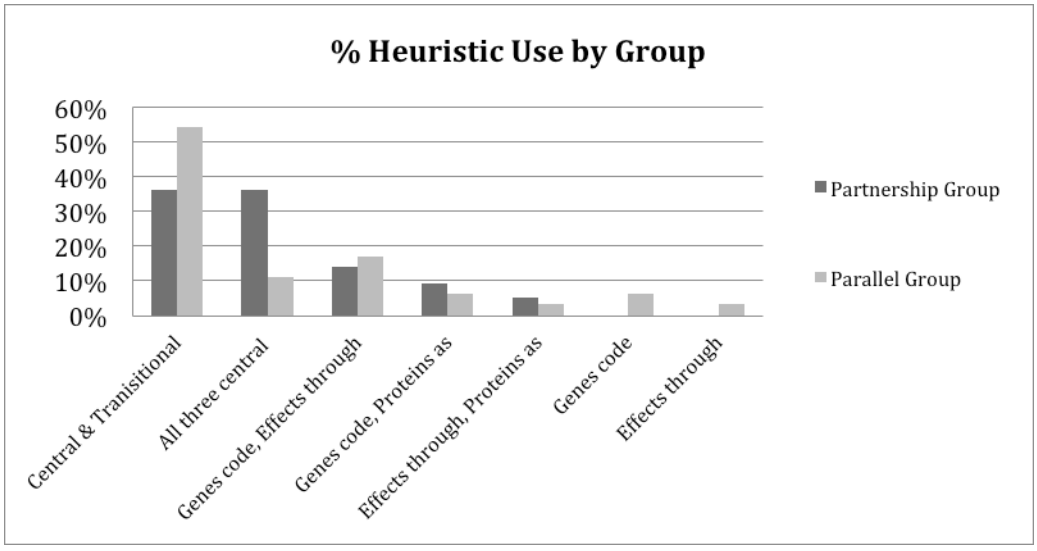


Figure 4.2. Use of heuristics during the interview by participants demonstrating parallel model reasoning (light grey bars) and partnership model reasoning (dark grey bars).

4.5.4.2 Use of schemas.

Heuristics are important in determining the specific conceptions individuals use to reason about a genetic phenomenon. Heuristics guide and constrain reasoning by providing principle-like knowledge pieces for developing explanations. Heuristics identify specific entities and the relationships between them. However, they are abstract knowledge representations and do not contain topic-specific details necessary for developing an explanation of a phenomenon. Domain-specific explanatory schemas, on the other hand, provide explanatory power by defining specific mechanisms that underlie phenomena within a domain. Together, heuristics and schemas provide a broad sense of the phenomenon that serves to constrain reasoning, as well as the fundamental details necessary for elucidating mechanisms. Therefore, we next examined the kinds of schemas participants invoked in conjunction with heuristics to develop and support their explanations.

Duncan (2007) identified several schemas in her study of undergraduate students' reasoning about genetics phenomena. For this study, we included three schemas identified in her study (*receptor, regulation,* and *structure/function*), and added three more based on analysis of participants' responses (*pathway, signal,* and *quantity*). In this section, and for the sake of brevity, we describe the *signal* schema in detail with the remaining schemas described in Table 4.5. The schema *signal* consists of three main slots for the constituents of the concept in question: (a) the molecule doing the signaling (a protein), (b) the directionality of the signal (where it comes from and where it is going), and (c) the outcome (what occurs when the signal is received). The constituent slots of this schema are constrained by the proteins as central heuristic - a protein is

usually the molecule sending the signal, or is the signal itself - and by the effects through interaction heuristic - the signaling molecule must interact with the receiving molecule in order for the signal to be transmitted. For example, in the following excerpt, Jamie, a genetic counselor uses the *signaling* and *pathway* schemas to describe how the protein derived from the mutated FTO gene may cause obesity by effecting appetite and metabolism.

Int	Do you think proteins have anything to do with this?
Jamie	Absolutely. Insulin and glucagon are two key factors in this. They actually tell your body how to break down foods. Your genes can only create a protein. The communication in your body is done through these proteins. Your genes aren't communicating anything, and proteins turn on or off parts of genes to create proteins through signaling pathways. I guess that the FTO gene mutation affects some sort of product that is part of the communication cascade. It might attach to certain cells to tell them to do this or that. Because the cascade is broken down because of the mutation, then you're changing it in a way that the person is affected.

Jamie suggests that a protein - like insulin or glucagon - is a major communication mediator in a "signaling pathway". The communications that are relayed via this signaling pathway are instrumental in cell function and, as explained by Jamie, changes in proteins - like the FTO gene mutation - ultimately lead to changes in the person. The *pathway* schema is exemplified when Jamie describes the communications that take place inside the cell. She states "the communication in your body is done through these proteins" and suggests that the product of the mutated FTO gene is "part of the communication cascade". The pathway schema is defined by the identification of a protein that is implicated in a process or pathway involving more than one protein that work in conjunction to create an effect. Here the communication cascade is comprises more than one protein relaying information in a cascade pattern that leads to a final

outcome - "the person is affected". This is different than the *signal* schema since this schema is defined by a protein that acts as a signal to mediate an outcome and is usually sent and received by something specific, such as a cell or receptor. This is exemplified when Jamie states how a "product" - likely a protein - "might attach to certain cells to tell them to do this or that". The interaction of a protein with a cell is the basis for the *signal* schema.

Table 4.5.
Description of schemas used by participants during the interview

Schema	**Definition**
Pathway	Protein is implicated in a process or pathway that involves more than one protein that work in conjunction to create an effect
Signal	Protein as a signal that mediates an outcome. Usually sent by and/or received my something specific
Receptor	Protein that acts as a receptor that receives a message (either protein or chemical)
Regulation of gene / protein expression	Molecular entities cause the differential expression of genes and/or proteins
Structure / function	Genes determine the structure proteins, this structure determines the function of the protein. Changes is the gene can cause structure/function changes in the protein
Quantity	Amount of protein or molecule present in a system causes an affect resulting in change in the entire system

Figure 4.3 illustrates the frequency with which participants using either the partnership or parallel model of reasoning draw on each schema. Participants most frequently in both reasoning groups used signaling and pathway schemas. Use of particular schemas did not appear to influence reasoning strategy across groups and nearly all participants used at least two schemas in their explanations, thus schemas are double coded in most instances and do not sum to 100% overall.

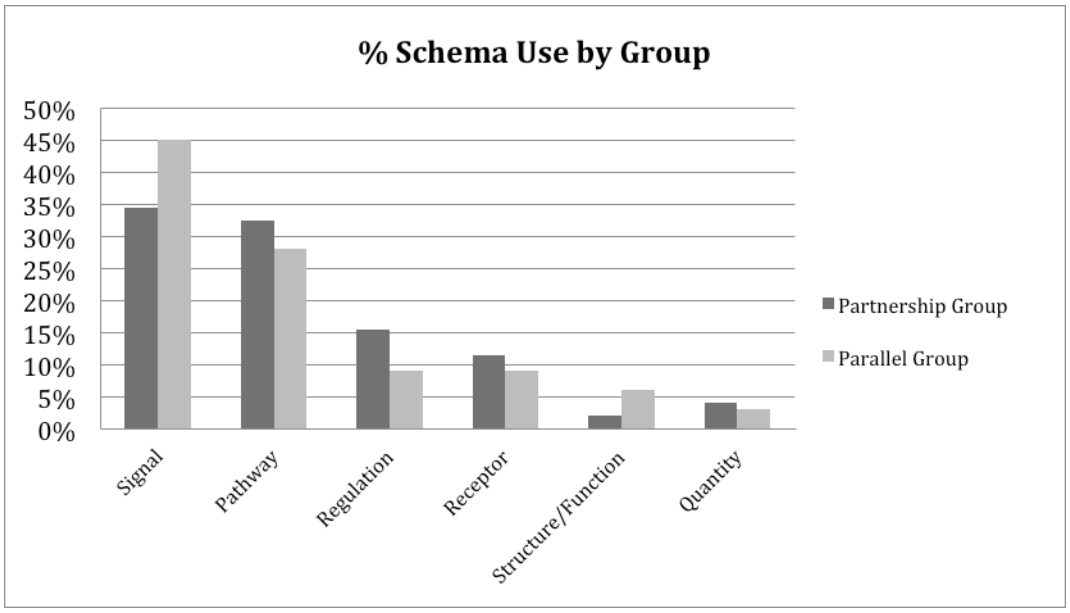


Figure 4.3. Use of schemas during the interview by participants demonstrating parallel model reasoning (light grey bars) and partnership model reasoning (dark grey bars).

4.5.4.3 Differences in explanation sophistication.

Schema use did not differ in meaningful ways between groups. However, we noticed that the overall level of detail provided in explanations differed. Participants who employed the partnership model of reasoning during the course of their interview provided the more detailed responses. To investigate the level of sophistication participants used to generate explanations, we developed a coding scheme (Table 4.6)

used to examine the heuristics and schemas used by participants in response to the molecular segment of the interview.

Table 4.6.
Levels of sophistication for ideas expressed by participants during the interview

	Level 1	**Level 2**	**Level 3**
General Overview	Use of heuristic(s) or schema(s) in explanation, but not both.	Use of heuristic(s) and schema(s) in explanation.	Use of heuristic(s) and schema(s) in explanation supported by mental models and propositions.

Responses fell into three general categories: (a) those that provided an explanation at the level of the organism and invoked heuristics or schemas, but not both (level 1), (b) those that included molecular entities in their explanations, and invoked heuristics and schemas (level 2), and (c) building on level 2, those that included mental models and/or propositional knowledge to exemplify how molecular entities can bring about the genetic phenomenon discussed in the interview task. The following three excerpts provide examples of participants' explanations at each level of sophistication.

Kristen, an undergraduate science major, provided her explanation for the phenomena at sophistication level 1:

Int So it's thought that the FTO gene effects appetite and metabolism, how do you think that might actually work?

Kristen So the mutation affects appetite through the brain, but metabolism is like digestive system and all that. Well maybe the brain sends out signals to control the whole body, so if the brain is affected its gonna affect metabolism and appetite.

Int Do proteins have anything to do with that?

Kristen **Proteins do work in the body (heuristic: proteins as central)**, so yeah they would be associated with that. If there were more proteins or something then he... this even relates to us eating a protein bar or something, we have more energy and its good for us. So if his body isn't

> creating enough protein or if it's too low, then maybe that causes his metabolism to be lower because metabolism requires energy to digest all the food.

Kristen acknowledges that signals relay information with resulting changes in appetite and metabolism ultimately leading to obesity in this case. She reasons that the brain interprets information for the body and thus signals for changes to occur. However, there is no mention of mediating factors or an explanation of how such changes could be carried out. Since Kristen does not invoke notions of proteins as mediators in this case, she is not using the schema *signal* even though she notes that signaling events occur. Even when Kristen is prompted to think about proteins as a mediating factor (i.e., "do proteins have anything to do with that?"), she acknowledges that proteins have functional roles in the body but cannot provide descriptions or examples of proteins as mediating genetic phenomena. In this case, she uses the heuristic proteins as central when she states, "proteins do work in the body" without employing a schema in her explanation. This is considered level 1 sophistication since she invokes a heuristic only and no schemas.

The majority of participants were able to at least use both heuristics and schemas in their explanations of the task phenomenon. Here Yujing, an undergraduate science major, demonstrates her understanding at a level 2 sophistication:

Int	So it's thought that the FTO gene effects appetite and metabolism, how do you think that might actually work?
Yujing	Perhaps it [the mutated FTO gene] makes him eat more because he becomes obese.... Or when your body is full, a signal is sent to the brain to say it’s full. Maybe his mutated FTO gene makes it so that the signal doesn't get sent right away or it’s very weak so the brain doesn't think its full even when the body knows its full. So he continues eating.
Int	So in that mechanism, what is the role of the FTO protein?

Yujing **The FTO protein would be the one sending the signal (heuristic: proteins as central)** back to the brain that the stomach is full. **So the mutated version wouldn't send up the signal or it would be very weak (schema: signal)**.

Yujing begins in a way similar to Kristen in that she conceives of a signal being sent to the brain from the body in order to perceive fullness after eating (level 1). She states that the mutated version of the gene delays or impedes the signal to some extent thus causing the individual to feel hunger despite having eaten. Yujing is prompted to consider protein as a mediating factor in this case (i.e., "what is the role of the FTO protein?"). Here her explanation rises to sophistication level 2 because she understands that the protein could mediate signaling and any change in protein would result in signal delay (level 2). This explanation invokes the proteins as central heuristics and the *signal* schema. She uses the heuristic and schema to support her explanation of a genetic mechanism. Yujing's notion of proteins as central is apparent since she states that the protein is what "[sends] the signal back to the brain". However, her explanation rests at a level 2 since she does not elaborate her explanation by providing mental models or propositional knowledge in order to support her explanation.

Along with the use of heuristics and schemas, some participants provided robust explanations that included mental models and propositions (level 3 sophistication). In the following excerpt, Bill, a science graduate student, demonstrates use of propositional knowledge:

Int So it's thought that the FTO gene effects appetite and metabolism, how do you think that might actually work?

Bill I would hypothesize it is affecting one directly or the other and then that's having affects. So I would say this gene is affecting your appetite in your

brain and your appetite is going to change your metabolism because you are eating more or less, so you see secondary affects in your metabolism or this gene is affecting your metabolism and thus you are having a different appetite. It is possible it is having a direct effect on both but they seem faraway places in the brain and your energy, so I think it would be one or the other directly.

Int Okay, so is it possible that the protein from this gene could be affecting both appetite and metabolism at the same time?

Bill Yes. If you had a gene affecting your metabolism directly, any **protein involved in your metabolism (heuristic: proteins as central)** that is not working 100%, and its working at 90% then your metabolism gets bumped to 90%, I feel like that would also affect your appetite. **If you have an insulin receptor site that is not working properly, your cells aren't going to know to take up glucose when insulin is out there (schema: receptor)**. You are going to have high blood sugar and a different metabolism because your insulin is not going to be recognized properly. If your blood sugar is high, that would cause you to eat less. It's still a change in your appetite. Let's say you have a change in a **gene that ends up overproducing the protein (heuristic: genes to proteins) insulin so your cells are always taking in sugar, so your blood sugar is always low, and you always feel hungry, you always have to eat, with all this energy your body just starts producing fat (schema: pathway)**. There are a lot of things that have to happen in metabolism. Our metabolism is all based on respiration, so we have to take sugar and it has to be broken down and it has to go through the Krebb's cycle. The Krebb's cycle has at least eight or nine really important enzymes [proteins]. If you can't encode one of those or it's working at like 98%, your metabolism is going to slow down. It is all connected. If this **gene is expressed in the brain (schema: gene expression)** it would make much more sense that it an appetite type gene, which is something that Mr. Oswald should talk to them about. Maybe his love for burgers is a genetic thing, and maybe not everyone has this. But the **protein produced by the gene (heuristic: genes to proteins)** is in very low amounts. It could be at higher amounts in his brain. If it is something found in his brain, it's actually more likely to have a secondary effect on metabolism and a direct effect on his appetite. I think **there are all sorts of networks that affect your appetite. If you disrupt any of that, it would have an effect on your appetite (schema: pathway)**.

Much like Kristen and Yujing, Bill begins by providing an explanation of the phenomenon without using specific heuristics or schemas. However, when prompted to consider how a protein may be involved in the mechanism, Bill launches into a detailed

account of cellular processes supporting metabolism and appetite. He uses all three central heuristics in his explanation as well as several schemas. What differs between his explanation (level 3) and Yujing's explanation (level 2), is that Bill elaborates by drawing on extensive propositional knowledge about the Krebb's cycle, cellular respiration, and blood glucose regulation to inform his explanation of changes in metabolic function and appetite. Participants that used relevant propositional knowledge in their explanations were more likely to demonstrate partnership reasoning. It is likely that the use of relevant propositional knowledge helped participants identify and integrate factors that influenced or contributed to the phenomenon in the reasoning task.

Figure 4.4 illustrates the distribution of participants by reasoning model according to level of sophistication provided in their explanations. Interestingly, only those participants who reasoned at a level 2 or 3 in terms of sophistication also provided responses throughout their interviews corresponding with the partnership model of reasoning (dark gray bars). Participants providing only a level 1 sophistication in their explanations were unable to also develop a partnership model of reasoning and instead used parallel reasoning. This suggests that, at minimum, use of heuristics and schemas in explanations supports partnership reasoning, and is further emphasized with the use of relevant propositional knowledge or mental models used to explain the phenomenon.

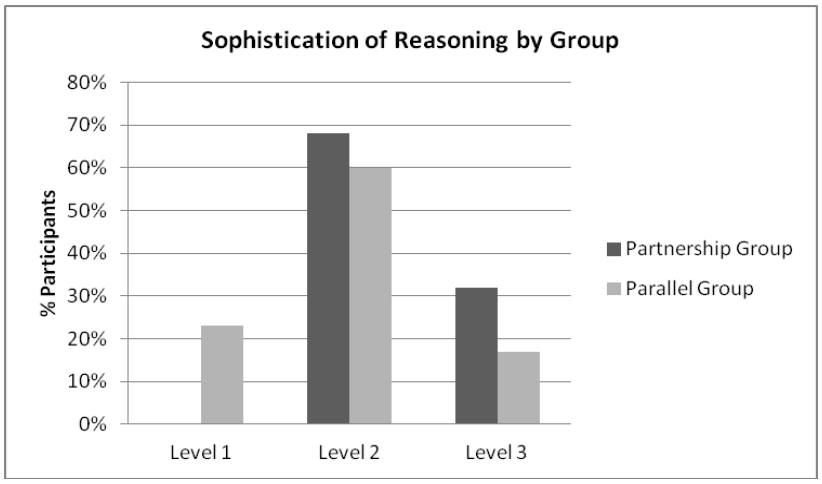


Figure 4.4. Sophistication of reasoning by participants during the interview demonstrating parallel model reasoning (light grey bars) and partnership model reasoning (dark grey bars).

4.5.4.4 Differences in reasoning within groups of participants.

In addition to individual participants' use of parallel or partnership model reasoning, we also noticed that specific sub-groups of participants demonstrated unique ways of reasoning within each model. In other words, not all participants used each model in identical ways. Table 4.7 indicates how four major sub-groups of participants are characterized based on different instantiations of each type of reasoning model.

Table 4.7.

Differences in reasoning within participant groups.

Participant Groups	Reasoning Model	Main Characteristics
Counselors & Graduate Science	Partnership	Use of heuristics, schemas, and propositional knowledge. Clearly define relationships between factors to explain phenomenon.
Graduate Philosophy	Partnership	Use of heuristics and schemas, no propositional knowledge. Identify generalized relationships between factors to explain phenomenon.
Graduate Philosophy	Parallel	Use of heuristics only or heuristics and schemas, no propositional knowledge. Difficulty describing molecular entities, often personify entities.
Undergraduate	Parallel	Use of heuristics only or heuristics and schemas, no propositional knowledge. Difficulty using domain knowledge in canonical ways.

Genetic counselors and science graduate students using the partnership model of reasoning do so with the greatest levels of specificity and draw on heuristics (mostly central heuristics), schemas, and propositional knowledge to support their explanations. These participants are able to identify contributing factors and clearly define the relationship between factors in ways that support their explanations of the phenomenon. For example, Laura a science graduate student opens her interview by identifying relationships between both environmental and genetic factors that contribute to Mr. Oswald's obesity:

Int Do you agree more with Mr. Oswald, or with the researchers, or think something else entirely about the link between genetics and obesity?

Laura It's really hard to tell in this case. Definitely his behavior is a factor. I mean obviously if you don't like to eat cheeseburgers - some people don't - you're less likely to have this outcome. However, if there is an appetite link it might lead him to crave more or maybe his own cravings will stimulate expression of this gene. So I think there might be some sort of genetic factor underlying it, but it's not the only case. I mean, genes and behavior can effect each other. So there may be a genetic component here. He might have certain parts of genes which affect how he metabolizes things or incorporates fats, or

> it could be him thinking about it [food] and the thought stimulates his appetite, but again it's also due to his tendency to eat these foods that this gene would even have an effect in the first place. You can't just say with this type of gene if it is a definitive affect of this, but also the fact that there is this particular allele for this gene present, you can't eliminate that it isn't playing a role.
>
> Int How come you can't just say it's genetic?
>
> Laura Well, it depends on the gene. Some variants of genes are all or nothing and will express a particular physical trait. But in this case, it seems to affect behavior, and in terms of genes that effect behavior - there's always a behavioral component such as accessibility to certain environmental factors and willingness to interact with certain environmental factors. So with a behavioral gene or something that is very environmentally influenced, there is going to be more variability.

In this excerpt, Laura identifies environmental and genetic factors that contribute to Mr. Oswald's obesity. What is unique about Laura's reasoning, and others like her, is that she is able to acknowledge the complex relationships that tie factors one another and to a disease state. Laura notes that accessibility to foods and choice of foods matters in terms of gene expression patterns that may lead to obesity by altering metabolic functions, but also that one would need to have this specific mutation in order to elicit the type of obesity Mr. Oswald is described to have in the story. As Laura's interview progresses, she draws on specific central heuristics, schemas, and propositional knowledge to support her explanation in the opening of the interview, typical of participants in this sub-group.

Philosophy graduate students were also included in this study to determine if well-developed reasoning skills and limited knowledge of genetics matter in terms of participants' ability to develop explanations about a genetics phenomenon. According to our knowledge assessment, the philosophy students in this study knew more about genetics than we had anticipated. In fact, they performed almost as well on the

knowledge assessment as the science graduate students and counselors and surpassed the undergraduate students (Table 4.3). Despite this, only four philosophy students used the partnership model of reasoning during the interview, while the remaining students used the parallel model of reasoning. This is similar to the undergraduate participants' performance - all used parallel reasoning during the interview.

One major difference between philosophy students who used the partnership model and the science graduate students and counselors who used the partnership model is the level of detail provided in terms of propositional knowledge. The philosophy students only provided heuristics and schemas in their explanations (level 2), while the science graduate students and counselors used either heuristics and schemas or were able to include robust propositional knowledge (levels 2 and 3). For example, James - a philosophy graduate student, demonstrates partnership model reasoning at level 2 in the following excerpt:

Int It's thought that the FTO gene effects appetite and metabolism, how do you think that might actually work?

James I don't think that this one gene is directly affecting both processes, but I think it could be that the **gene codes for a protein (heuristic: genes code for proteins) that controls metabolism and then indirectly affects other proteins (heuristic: effects through interaction) that control appetite (heuristic: proteins as central)** or something like that. The FTO protein could have an effect on certain hormones that **regulate these processes (schema: regulation)** and they are not being excreted as they normally should because of this mutation.

Int So what does it tell you about this mutation that some of Mr. Oswald's family members are also obese?

James Well perhaps there's more than one gene at play here. It's possible that other **genes control the expression of FTO (heuristic: genes as active)** and then depending on those combinations it determines obesity for different individuals. It's also possible that the environment may influence expression of FTO. Some combination of these factors that the parents were exposed to

prevented them from becoming obese.

Characteristic of partnership model reasoning, James identifies specific factors that may influence obesity - other genes and their combinatorial effects and the notion that the environment can influence gene expression. James believes a combination of these factors explain changes in appetite and metabolism and may have influenced obesity in Mr. Oswald's family members. James applies central and transitional heuristics and the *regulation* schema in his explanation, but could not offer further details about the mechanism underlying this phenomenon. James can only say that "some combination of these factors" are what contribute to the phenomenon. Acknowledgement of a relationship between factors is necessary for partnership model reasoning, however James responds only in general terms unlike the counselors and science graduate students previously mentioned. This level of description is typical of philosophy students using the partnership model of reasoning.

The majority of philosophy graduate students (67%), however, use the parallel model of reasoning in similar ways as the undergraduate science students. These participants tend to draw on central and transitional heuristics and/or schemas to support their explanations. Philosophy students who used parallel model reasoning during the interview were more likely to struggle with providing explanations at the sub-cellular level (i.e., explanations that included molecular entities). For example, Jeff - a philosophy graduate student, provides his explanation of the phenomenon:

Int	So it's thought that the FTO gene effects appetite and metabolism, how do you think that might actually work?
Jeff	So there'd be some form of neurotransmitter that would be encoded by the gene and produced by the cell and different levels would then influence the appetite signaling to the individual that they are hungry

or not hungry or increase their desire for certain foods. I'm not sure how a mutation in a brain cell would affect metabolism, unless it has some intermediate step like it increases the desire to want to perform certain activities that are then relevant to your metabolism. Like maybe it's different levels of physical activity that are correlated with rate of metabolism. So maybe if a change in your brain causes you to want to do specific activities then that might then influence your metabolism.

Int Would proteins have anything to do with that?

Jeff Yeah, I would think so... but I'm really not sure how.

Jeff's explanation draws on notions of genes as productive instructions to generate a physical entity - in this case a neurotransmitter. This instance is the only direct reference Jeff makes to molecular entities and their role in the phenomenon. From this point forward, Jeff describes events that are non-genetic such as "desire to want to perform certain activities" and changes in the brain cause "you to want to do specific activities". In general philosophy students using the parallel model of reasoning tangentially work molecular entities into their explanations that ultimately result in explanations that have more to do with personification of entities and their behaviors than genetics.

Undergraduate participants were more likely to draw on notions of molecular entities, but often struggled to use their ideas in domain appropriate ways or provide details necessary for explaining the role of molecular entities in the phenomenon. For example, Mike - an undergraduate student, offers his explanation of the phenomenon:

Int So it's thought that the FTO gene effects appetite and metabolism, how do you think that might actually work?

Mike I feel like the gene transcribes the proteins that activate certain parts of the brain that increase appetite or decrease metabolism.

Int How do you think a protein might increase appetite? Is there a job a protein could do for that to happen?

Mike I feel like it could increase the amount of information that's sent to the brain or maybe send the wrong information - like telling a person that they're hungry when they aren't and causing them to eat more than they would usually eat.

Int So the protein is the signal that controls appetite. What about metabolism in this case?

Mike I feel like if it [the protein] slows the metabolism down it would decrease the function of the organs in the body and cause him to use less energy. All the nutrients are stored and not used up.

In this case, Mike offers an explanation that is based on notions of proteins as central to the phenomenon, but he struggles to provide details of function. He believes that proteins can "activate certain parts of the brain that increase appetite or decrease metabolism", but to what extent and how this occurs is not described by Mike. When prompted, Mike suggests that changes in the protein may affect the volume of "information" being sent to the brain, but the most he can convey is that somehow appetite increases and metabolism decreases resulting in obesity. The type of information and its affects are not described.

In general, both philosophy graduate students and undergraduate students using parallel model of reasoning struggled to explain the mechanism underlying obesity. They provided explanations that were limited to the use of heuristics and schemas and lacked the details explicated in the propositional knowledge of science graduate students and counselors. This suggests that well developed reasoning skills are helpful in considering genetics phenomena, but may afford little in terms of sophistication of reasoning patterns due to the need for robust domain-specific knowledge.

4.6 Discussion

Scientific phenomena are generally multi-factorial, with factors influencing each other in complex ways. For example, deciding whether to purchase genetically modified or non-modified foods at the grocery store may include factors that are scientific in nature such as the process of generating genetically modified foods, and non-scientific factors such as cost. The ability to identify and coordinate evidence to develop theories and explanations about a phenomenon is a major component of science literacy (Kuhn, Schauble, & Garcia-Mila, 1992; Morris, Crocker, Masnick, & Zimmerman, 2012). In the following sections we discuss differences in scientific reasoning, strategies applied by participants in this study, and implications for scientific literacy.

4.6.1 Difference in Scientific Reasoning

Identifying relevant evidence and explaining how they causally contribute to a phenomenon - or not - are important components of scientific reasoning. Deciding on inclusion and exclusion of evidence is not a trivial feat and one that children and adults equally struggle with (Chinn & Brewer, 1998; Schauble, 1996). Kuhn, Schauble, and Garcia-Mila (1992) suggest that difficulty defining valid factors that influence an outcome and how they relate to one another has less to do with content knowledge, but instead more to do with theories and beliefs about a phenomenon. In Kuhn et al.'s (1992) work, children's theories guided their attention to evidence or factors that may influence the outcome of reasoning tasks they encountered. Thus, the theories one applies to investigate or explain a phenomenon may limit or afford attention to evidence and can determine how factors are associated to explain the phenomenon. It is likely that participants with well developed heuristics and schemas of genetic mechanisms are likely

to generate a partnership model of reasoning from the ill-defined evidence presented in this study's reasoning task (i.e., the ability to validly include or exclude evidence and coordinate theory and data to explain the phenomenon). Based on the results of this study, the use of central heuristics and the ability to explain heuristics and schemas using propositional knowledge and mental models directly contributes to the sophistication of participants' scientific reasoning.

The concept of relationships is at the heart of the partnership model. We hypothesize that individuals using the partnership model of reasoning are better prepared to generate informed action plans or make decisions about a phenomenon. Essentially, the partnership model of reasoning informs individuals' ability to identify the factors contributing to the phenomenon, to explain why the phenomenon is occurring by integrating multiple pieces of evidence, and to generate an informed action plan or make decisions. This method of reasoning is not fail-proof, but it does afford individuals the ability to revise and recreate decisions based evidence.

The parallel model of reasoning is somewhat less sophisticated than the partnership model. Participants are able to identify relevant pieces of evidence that contribute to the phenomenon based on their understandings and prior conceptions of biological systems as well as information acquired from the task. However, this model of reasoning only affords the ability to identify evidence, understanding how evidence is integrated to explain the phenomenon is limited. As Kuhn et al. suggest, "Acquisition of content within knowledge domains does not by itself explain scientific thinking development" (Kuhn, Schauble, & Garcia-Mila, 1992, p. 321). Thus, the limited ability to coordinate evidence is not necessarily resulting from lack of extensive and deep content

knowledge. Evaluation and coordination of data in order to support reasoning involves targeted instruction and assessment (Means & Voss, 1996; Zohar & Nemet, 2002). Identifying the theories one holds about genetic mechanisms (i.e., heuristics and schemas) is critical for determining what students know and how curricular interventions can support the development of partnership model reasoning.

4.6.2 Examining Participants' Reasoning Strategies

One question addressed in this study is why differences in reasoning strategies - parallel and partnership models - exist. Content knowledge is one salient means for determining reasoning differences because the nature of the task presented in the interview required participants to draw on their knowledge of genetics to generate and support claims. We hypothesized that determining differences in content knowledge use would shed light on differences between groups of participants in terms of reasoning ability. Our analysis demonstrated that participants using central heuristics, more than one schema, and extensive propositional knowledge and mental models were more likely to apply the partnership model of reasoning. These participants were also more likely to identify multiple pieces of causal evidence supporting the phenomenon and theorize about the relationship between their ideas. It is critical to couple central heuristics with sophisticated schema explanations in order to support partnership reasoning. It was not apparent from our analysis if the use of particular schemas mattered for partnership reasoning. Nearly all participants used at least the *signal* or *pathway* schemas in their explanation. However, those participants using the partnership model of reasoning provided relevant propositional knowledge about schemas more frequently than those participants using the parallel model. In other words, robust reasoning skills are derived

from canonical content knowledge and one's ability to coordinate theory and data (Means & Voss, 1996; Zohar & Nemet, 2002).

Not all participants with robust understandings applied the partnership model of reasoning during the interview - only 37% did so. This group was entirely comprised of practitioners (genetic counselors) and graduate students (both science and philosophy). It is not surprising that counselors and science graduate students were able to apply the partnership model of reasoning to the interview task since they completed extensive coursework in genetics and discuss genetics issues with patients and students on a daily basis. What was unexpected was that a substantial percentage of the philosophy graduate students (33%) were able to do so as well. In addition to this, the philosophy graduate students, using either model of reasoning, scored nearly as high as the science graduate students and counselors on the content knowledge survey (philosophy students: 92% correct overall; science graduate students and counselors: 95% correct overall).

Although none of the philosophy graduate students had completed genetics coursework in higher education (all had completed at least one high school biology course), approximately half of the group studied philosophy of science in their doctoral career - albeit philosophy of the physical sciences. In addition, this participant group had completed extensive coursework on logic and reasoning and formal and informal argumentation as part of their doctoral requirements. Together, these factors may contribute to philosophy graduate students' improved assessment scores and reasoning ability during the interview. We suspect that studying both formal and informal reasoning improved philosophy students' ability to read questions carefully and "logic through" what might be the correct answers on the survey. The same holds true for their reasoning

during the interview task. However, in terms of content knowledge use, the philosophy students frequently used transitional heuristics during the interview and did not use propositional knowledge to expand their explanations. This is not surprising since philosophy students did not complete any graduate level courses on molecular genetics. However, one third were able to demonstrate partnership model reasoning during the interview. This suggests that philosophy students' well developed reasoning skills supported their ability to generate theories and evaluate data more so than those without similar training, such as participants in the undergraduate student group.

Another surprising finding was the lack of partnership reasoning across science undergraduate students. All of the participants in this group developed explanations indicative of parallel reasoning and had difficulty defining the relationships between pieces of evidence contributing to the phenomenon. They also scored significantly lower than the other three participant groups (74% correct overall) on the content knowledge survey. This finding is surprising since these students have more than a passing interest in the sciences - nearly all of the participants in this group intend to major in the biological and health sciences - and they had all recently completed two semesters of general biology coursework that included several weeks of genetics instruction. Although these participants had little or no formal training in scientific reasoning, we expected that they would at least surpass the philosophy students in terms of content knowledge.

This suggests that sophisticated knowledge representations (e.g., central heuristics) are important for supporting integrated reasoning strategies. This is exemplified by the undergraduate students limited understanding of genetics and in turn their limited ability to apply the partnership model of reasoning. However, it seems that

highly developed reasoning skills can on occasion circumvent the need for deep knowledge of a domain. This is exemplified by the philosophy graduate students' ability to nearly match the science graduate students and counselors' knowledge survey scores and for a third to apply the partnership model of reasoning during the interview task. It is important to note however that the counselors - with the most developed content knowledge - were more likely as a group (73%) to apply partnership reasoning to the interview task than any other participant group. The counselors often drew on actual examples they encountered in their work with patients to explain the phenomenon presented in the interview task and even offered suggestions about future studies that could be conducted to improve the data presented in the task. Robust content knowledge along with experiential knowledge proved helpful for the counselors' ability to reason about the phenomenon as they were most likely to apply the partnership model of reasoning.

It is also possible that other factors not measured in this analysis could contribute to a participants ability to apply the partnership model (especially those of the philosophy graduate students). It is likely that interest, familiarity, personal opinion about genetics issues, and task composition (i.e., situational features) also play a role in terms of how individuals - with varying content knowledge - reason about an issue. However, it is clear that canonical understandings and one's ability to relate core ideas across the domain are indicative of one's ability to reason in sophisticated ways.

4.7 Implications

Although this study featured small groups of participants (fifteen in each) limiting the impact of generalizations, specific implications can be drawn from our findings. First,

it appears that experiential knowledge of genetics mattered in terms of using the partnership model of reasoning. The genetics counselors, each with a Master's degree in genetic counseling and a minimum of two years of practice in the field, most often applied partnership model reasoning during the interview. It is likely that their experiences with patients discussing various examples of complex genetic disorders provided unique insight while thinking about the interview prompt. This finding suggests that reasoning about a variety of ill-structured and complex phenomena may prove useful in supporting more sophisticated methods of reasoning among students. Including a variety of phenomena during genetics instruction - especially those that have many plausible explanations could increase students' genetics literacy and reasoning ability. Those participants able to apply the partnership model of reasoning were more capable of identifying factors that contribute to the phenomenon and integrating factors in their explanation. Particular heuristics, schemas, and the use of relevant propositional knowledge supported participants ability to apply this more sophisticated reasoning strategy. Thus, the presence of distinct and hierarchal models of reasoning demonstrates the need for targeted instruction and assessment to support the development of effective reasoning skills. We suspect that these models of reasoning are not constrained to genetics, but are transferrable and relevant to all scientific domains.

A second implication of this work is the role of engagement with argumentation practices as a means for supporting more sophisticated patterns of reasoning. Philosophy students in this study received little training in genetics, yet as part of their degree program they engaged in several courses that included the study of formal and informal argumentation. It must be noted, however, that the participants in this study were

recruited on a volunteer basis. This may have encouraged those interested in genetics, or science in general, to participate and dissuaded those indifferent to science from participating. This was especially the case with the philosophy students who were mostly philosophy of science students (albeit physical sciences). Despite this, it is possible that their skill at analytical thinking (analyzing the relevance of evidence) likely contributed to their reasoning about the interview task. This suggests that equal emphasis should be placed on the development of argumentation skills along with the development of robust domain-specific knowledge in science classrooms.

Although the results of this study do not translate directly to other populations (e.g., those not engaged in higher education), it does provide an "upper anchor" for science literacy. Further studies are needed to determine how students at in K-12 science classrooms reason about similar phenomena as the kind presented in this study. It is possible that other models of reasoning can be parsed with the inclusion of a greater diversity of participants and that more robust reasoning skills can be developed at a younger age than the undergraduate level. Studying how students reason about authentic issues in genetics, and other domains, may provide insight into curricular changes required to further develop reasoning ability.

Chapter 5: Conclusion

5.1 Introduction

With rapid advancements in science, greater emphasis is placed on citizens to make informed decisions about socio-scientific issues they encounter in their daily lives. However, we know little about how individuals use their knowledge of science to develop explanations about socio-scientific issues. Studies that explore reasoning about these issues generally focus only on what individuals know about the domain or additionally examine the structural quality of the arguments individuals generate (e.g., Bowling et al., 2008; Sadler & Donnelly, 2006). One major consideration that is often overlooked, is how individuals with varying knowledge in a domain reason about issues cast in a variety of issues. The main contribution of this dissertation is to elucidate the interaction of content knowledge use, argument generation, and the role of situational features in reasoning about authentic genetics issues. Considering all three aspects provides a clearer picture of what it means to be scientifically literate. Working within the new paradigm of the empirical approach to scientific literacy, this dissertation provides evidence of the challenges of understanding and reasoning about authentic genetics issues.

5.2 Findings and Implications

Findings from these studies demonstrate that domain-specific knowledge and reasoning ability matter as individuals consider genetics phenomena cast in a variety of issues. As demonstrated in Chapter 2, late career undergraduate students reasoned equally well across two issues in terms of content knowledge use and argument quality. Early career undergraduate students reasoned better about the human task versus the plant task. This is likely due to differences in reasoning ability across issues. Experts, in the fields of

science and science education, frequently make the assumption that individuals use their scientific content knowledge to reason equally well across different issues (Feinstein, 2011). However, studies in educational psychology and cognitive science suggest that situational features of issues can influence how individuals perceive and reason about problems (e.g., Bransford & Schwartz, 1999; Ceci & Ruiz, 1993). Thus, situational features must be acknowledged when investigating science literacy in any domain. One implication of this work is the role of situational features in reasoning.

Given that situational features can influence reasoning, it was important to consider what kinds of genetics issues the public is likely to encounter in their daily lives and the knowledge required to understand such issues. Chapter 3 demonstrates that common phenomena and situational features arise in news articles discussing genetics issues. The majority of articles analyzed in Chapter 3 include a story about a human genetic disorder of a physiological nature that is characterized or treated with the application of a genetic technology. Knowledge requirements anticipated as necessary for understanding issues cast in this context demonstrate the need for robust knowledge of key genetics processes such as the nature of genetic mutations and their role in protein synthesis. Our analysis suggests that education initiatives may need to be expanded in order to emphasize these key processes.

Examining and characterizing authentic issues and knowledge requirements leads to questions about how individuals reason about issues comprised of the common situational features identified in Chapter 3. Findings from Chapter 4 demonstrate that individuals with varying genetics knowledge and argumentation ability apply specific reasoning strategies to generate and support their position about a phenomenon.

Participants using sophisticated knowledge representations were more likely to integrate evidence from the task with their prior knowledge to develop and support their explanation of the phenomenon. Participants with limited or less sophisticated notions of genetics were more likely to identify key pieces of information as relevant in their explanations, but had difficulty integrating their ideas to generate a coherent explanation about the phenomenon.

Findings from this dissertation suggest that knowledge use, argument ability, and familiarity with the situational features of a reasoning task matter in terms of informing how individuals perceive and reason about a socio-scientific issue (Figure 5.1).

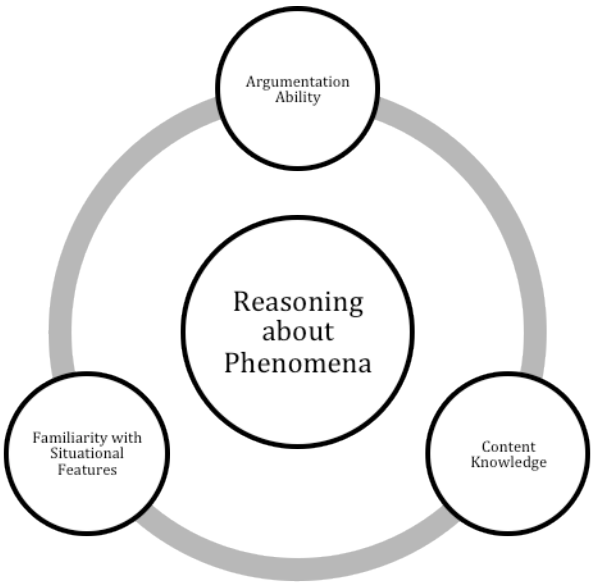


Figure 5.1. Three aspects that influence reasoning about genetics phenomena.

Determining the relationship between these aspects is difficult to predict since individuals vary in terms of the sophistication of their content knowledge, their argumentation ability, and the ways in which situational features may influence how they think about a phenomenon. This work suggests that reasoning patterns do exist given individuals' use

of specific knowledge representations. However, it also appears that well developed reasoning abilities may circumvent the need for highly specific domain knowledge. Further studies are required in order to parse out the ways in which these three aspects inform reasoning about phenomena.

It is likely that more reasoning models than just parallel and partnership exist. This may be elucidated with the inclusion of more diverse sets of participants. For example, middle and high school students may reason differently about the phenomenon presented in Chapter 4. Given what is described in the research literature on genetics education, it is likely that middle and high school students will be able to identify factors as they relate to the phenomenon, but have difficulty relating factors (characteristic of the parallel model of reasoning). Where they may differ from participants in this study is in their ability to use canonically accurate understandings of genetics to identify contributing factors. Many students at the middle and high school levels hold alternative conceptions about genetics and the causal mechanisms underlying genetic phenomena. The parallel model of reasoning assumes the individual has at least basic, canonical understandings of genetics demonstrated by the use of central heuristics. Individuals with limited knowledge of the central heuristics may find it difficult to identify relevant factors that can explain a phenomenon. Such a naive model of reasoning would be considered less sophisticated than the parallel model of reasoning (Figure 5.2).

It is also possible that a model of reasoning exists between that parallel and partnership models of reasoning in terms of sophistication. This transitional model may feature characteristics of both models. Individuals using the transitional model may be able to identify factors and hint at the relationship between them. For example, a few of

the philosophy students demonstrated their ability to identify relevant factors, but could only say that they are somehow related in generating the phenomenon (Chapter 4). They were unable to explicate how such factors are related (a characterizing feature of the partnership model). The transitional model is thus a significant step in the development of reasoning skills and could be short-lived with targeted instruction that illuminates causal mechanisms of phenomena (Figure 5.2).

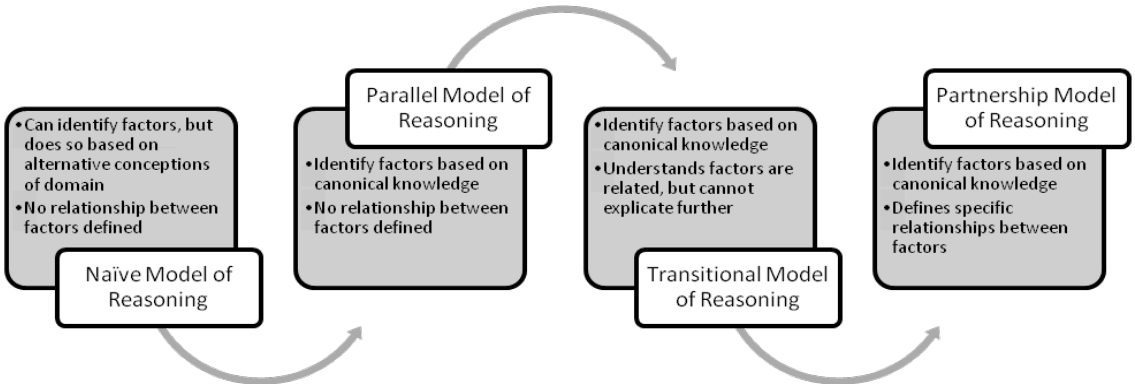


Figure 5.2. Hypothetical trajectory of reasoning models from least to most sophisticated.

It is still unclear if the hypothetical trajectory identified in figure 5.2 is the only path to partnership model reasoning or if varying sub-paths exist that include other models of reasoning that are equally productive. It is also unclear if these models are relevant outside of the reasoning task presented in Chapter 4 or even outside of the genetics domain. It is conceivable that such models of reasoning transcend content-specific topics and can be attributed to a greater variety of phenomena that are mechanistic in nature such as phenomena related to climate change, evolution, or chemical reactions. This dissertation suggests that specific aspects of literacy exist that promote deeper thinking and more sophisticated reasoning by individuals possessing the skills identified in figure 5.1. Further studies are required in order to elucidate how

individuals deepen their reasoning over time, especially under the auspices of targeted instruction and experiential learning.

5.3 Future Research

Based on the findings of this work, three areas of study warrant further investigation: (a) further investigation of common phenomena and situational features that arise in a variety of media sources, (b) an investigation of reasoning strategies that arise as lay individuals consider issues across multiple issues, and (c) a longitudinal analysis of the development of reasoning about socio-scientific issues. Qualitative analysis would lend merit to these studies in order to capture the richness of media representations and participants' ideas and explanations.

Expanding the analysis of media sources from news articles to also include science TV programs, Internet sites describing science issues, and science magazines written for lay audiences casts a wider net to investigate common phenomena and situational features encountered in the world. Expanding the time frame from two years to five or ten years may also improve the characterization of common phenomena as major events can change how media coverage is portrayed from year to year. This research may identify common situational features not captured in this dissertation and lend authenticity to reasoning tasks developed in future studies. It is likely that several common issues are portrayed in the media. This dissertation investigated one, but it is likely that more exist. From this analysis, multiple reasoning tasks could be developed for future studies.

Examining how individuals with varying genetics knowledge and reasoning ability considered one reasoning task (Chapter 4) was helpful in identifying specific

reasoning strategies. However, it would be interesting to test my theoretical assumptions about other reasoning models (figure 5.2) to determine if reasoning strategies are similar among lay individuals and if and how reasoning strategies change across issues. Participants would be presented with multiple reasoning tasks. Analysis would include assessing use of knowledge representations and ability to generate and support claims. Findings from this analysis would be important for understanding how lay individuals consider authentic science issues and how they transfer their understandings across issues comprised of varying situational features.

Considering that different reasoning strategies do exist for individuals with varying knowledge and reasoning ability and that some reasoning strategies are more sophisticated than others, leads to a third study that explores the development of reasoning strategies over time. In this case it would be important to include participants from many levels of education such as middle and high school students, undergraduate and graduate students, and non-college attending adults participants. Participants would be asked to consider several reasoning tasks and knowledge use and reasoning ability assesses. Findings from this work may inform the development of curricular interventions that provide targeted instruction of critical content knowledge and argument skills that support more sophisticated models of reasoning.

References

23andMe. (2012). Retrieved from: https://www.23andme.com/

American Association for the Advancement of Science [AAAS]. (2001). Atlas of science literacy. Washington, DC: Author.

American Association for the Advancement of Science [AAAS]. (2011). *AAAS project 2061 science assessment website.* Retrieved from http://assessment.aaas.org/pages/home.

Anderson, R.D. & Helms, J.V. (2001). The ideal of standards and the reality of schools: Needed research. *Journal of Research in Science Teaching, 38*(1), 3 - 16.

Associated Press. (2010, October 25). Circulation numbers for the 25 largest newspapers. *The Boston Globe.* Retrieved from http://www.boston.com/business/articles/2010/10/25/circulation_numbers_for_the_25_largest_newspapers/

Bahnoo, S.N. (2011, August 5). No prints? Evidence points to a mutated gene. *The New York Times*. Retrieved from: http://www.nytimes.com/2011/08/09/science/09obprint.html?scp=8&sq=gene&st=nyt

Baskaran, A., & Boden, R. (2004). Science: A controversial commodity. *Science, Technology, & Society, 9*(1), 1 - 26.

Bates, B.R. (2005) Public culture and public understanding of genetics: A focus group study. Public Understanding of Science, 14 (47 – 65).

Bauer, M.W. (2009). The evolution of public understanding of science: Discourse and comparative evidence. *Science, Technology, & Society, 14*(2), 221 - 240.

Bellcross, C.A., Page, P., & Meaney-Delman, D. (2012). Direct-to-consumer personal genome testing and cancer risk prediction. *The Cancer Journal, 18*(4), 293 - 302.

Berland, L.K. & McNeill, K.L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. Science Education, 94, 765 – 793.

Bowles, S. & Gintis, H. (1976). *Schooling in capitalist America: Educational reform and the contradictions of economic life.* New York: Basic Books.

Bowling, B.V., Huether, C.A., Wang, L., Myers, M.F., Markle, G.C., Dean, G.E., Acra, E.E., Wray, F.P., Jacob, G.A. (2008). Genetic literacy of undergraduate non-science majors and the impact of introductory biology and genetics courses. BioScience, 58(7) 654 – 660.

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. *Review of Research in Education, 24*, 61-100.

Brenner, M.E. (2006). Interviewing in educational research. In J.L. Green, G. Camilli, P.B. Elmore (Eds.). Handbook of complementary methods in education research, (pp. 357 – 370). Washington, D.C.: American Education Research Association.

Bryce, T.G.K., & MacMillan, K. (2009). Momentum and kinetic energy: Confusable concepts in secondary school physics. *Journal of Research in Science Teaching, 46*(7), 739 – 761.

Bybee, R., Fensham, P.J., Laurie, R. (2009). Scientific literacy and contexts in PISA 2006 science. *Journal of Research in Science Teaching, 46*(8), 862 - 864.

Ceci, S.J., & Ruiz, A.I. (1993). Inserting context into our thinking about thinking: Implications for a theory of everyday intelligent behavior. In M. Rabinowitz (Ed.). Cognitive science foundations of instruction, (pp. 173 – 188). Hillside, NJ: Lawrence Erlbaum Associates.

Cerbin, W. (1988, April 24 - 27). The nature and development of informal reasoning skills in college students. Paper presented at the Twelfth National Institute on Issues in Teaching and Learning. Chicago, IL.

Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences, 6*(3), 271–315.

Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5(2), 121–152.

Chin, C., & Osborne, J. (2010). Supporting argumentation through students' questions: Case studies in science classrooms. Journal of the Learning Sciences, 19, 230 – 284.

Chinn, C. A., & Brewer, W. F. (1998). An empirical test of a taxonomy of responses to anomalous data in science. *Journal of Research in Science Teaching, 35*(6), 623-654.

Clough, E.E., & Wood-Robinson, C. (1985). Children's understanding of inheritance. *Journal of Biological Education, 19*, 304–310.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd Ed.). Hillsdale, NJ: Erlbaum. In D. N. Perkins, & J. W. Segal (Eds.), *Informal reasoning and education* (pp. 83 – 105). Hillsdale, NJ: Erlbaum.

Condit, C.M. (2010). Public understanding of genetics and health. *Clinical Genetics, 77,* 1 – 9.

de Vries, H., Mesters, I., van de Staag, H., Honing, C. (2005). The general public's information needs and perceptions regarding hereditary cancer: An application of the integrated change model. *Patient Education and Counseling, 56,* 154 – 165.

DeBoer, G.E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582 - 601.

diSessa, A.A. (1988). Knowledge in pieces. In G. Forman & P. Pufall (Eds.), *Constructivism in the computer age* (pp. 49–70). Hillsdale, NJ: Erlbaum.

Donovan, J. & Venville, G. (2012). Exploring the influence of mass media on primary students' conceptual understanding of genetics. *International Journal of Primary, Elementary and Early Years Education, 40*(1), 75 - 95.

Duncan, R.G. (2007). The role of domain-specific knowledge in generative reasoning about complicated multi-level phenomena. *Cognition & Instruction, 25*(4), 271 - 336.

Duncan, R.G., & Reiser, B.J. (2007). Reasoning across ontologically distinct levels: Students' understandings of molecular genetics. *Journal of Research in Science Teaching, 44*(7), 938 – 959.

Duncan, R.G., Rogat, A.D., Yarden, A. (2009). A learning progression for deepening students' understandings of modern genetics across the 5th – 10th grades. *Journal of Research in Science Teaching, 46*(6), 655- 674.

Duncker, K. (1945). On problem solving. *Psychological Monographs,58*(5, Serial No. 113).

Duranti, A., & Goodwin, C. (Eds.). (1992). Rethinking context: Language as an interactive phenomenon. Cambridge, UK: Cambridge University Press.

Dytham, C. (2003). Choosing and using statistics: A biologist's guide (2nd Ed.). Malden, MA: Blackwell Publishing.

Elo, S. & Kyngas, H. (2007). The qualitative content analysis process. Journal of Advanced Nursing, 62, 107-115.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education, 88*(6), 915–933.

Feinstein, N. (2009). Prepared for what? Why teaching "everyday science" makes sense. *Phi Delta Kappan, 90*(10), 762 - 766.

Feinstein, N. (2011). Salvaging science literacy. *Science Education, 95*(1), 168 – 185.

Feinstein, N.W., Allen, S., & Jenkins, E. (2013). Outside the pipeline: Reimagining science education for nonscientists. *Science, 340*, 314 - 317.

Feldman, E.A. (2012). The genetic information nondiscrimination act [GINA]: Public policy and medical practice in the age of personalized medicine. *Journal of General Internal Medicine, 27*(6), 743 - 746.

Fleming, R. (1986a). Adolescent reasoning in socio-scientific issues, part I: Social cognition. *Journal of Research in Science Teaching, 23*, 677 – 687.

Fleming, R. (1986b). Adolescent reasoning in socio-scientific issues, part II: Nonsocial cognition. *Journal of Research in Science Teaching, 23,* 689 – 698.

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education, 92*(3), 404 - 423.

Freidenreich, H.B., Duncan, R.G., & Shea, N.A. (2011). Exploring middle school students' understanding of three conceptual models in genetics. *International Journal of Science Education*, 33(17), 2323-2350.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12,* 306–355.

Ginsburg, H. P. (1997*). Entering the child's mind: The clinical interview in psychological research and practice.* New York: Cambridge University Press.

Greeno, J. G. (2006). Learning in activity. *Cambridge handbook of the learning sciences* (pp. 79-96). New York: Cambridge University Press.

Greeno, J. G., Collins, A. M., & Resnick, L. B. (1996). Cognition and learning. In D. C. Berliner, & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 15-46). New York: Macmillan.

Hawkins, A.K. & Ho, A. (2012). Genetic counseling and the ethical issues around direct to consumer genetic testing. *Journal of Genetic Counseling, 21*(3), 367 - 373.

Henderson, B.J., & Maguire, B.T. (2000). Three lay mental models of disease inheritance. Social Science & Medicine, 50(2), 293 – 301.

Heredia, S., Furtak, E.M., & Morrison, D. (2012, March). Item context: How organisms used to frame natural selection items influence student reasoning choices. Paper

presented at the Annual Meeting of the *National Association of Research on Science Teaching*, Indianapolis, IN.

Hofstein, A., & Rosenfeld, S. (1996). Bridging the gap between formal and informal science learning. *Studies in Science Education, 28,* 87 - 112.

Hogan, K. (2002). Small groups' ecological reasoning while making an environmental management decision. *Journal of Research in Science Teaching, 39*, 341 – 368.

Hsieh, H.F., & Shannon, S.E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research, 15*(9), 1277 – 1288.

Hurd, P. D. (1958). Science literacy: Its meaning for American schools. *Educational Leadership, 16*, 13 – 16.

Hurd, P.D. (1998). Scientific literacy: New minds for a changing world. *Science Education*, 82, 407 - 416.

Inhelder, B. & Piaget, J. (1958). *The growth of local thinking from childhood to adolescence.* New York: Basic.

Irwin, A., & Wynne, B. (1996). *Misunderstanding science?* Cambridge: Press Syndicate.

Jamieson, A. (2009, September 3). Black parents have three white children. *Telegraph.* Retrieved from http://freddyo.com/2009/09/04/black-couple-has-5-kids-three-with-white-skin/

Jiménez-Aleixandre, M.P., Rodríguez, A.B., Duschl, R.A. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education, 84,* 757 – 792.

Jones, J. & Himelboim, I. (2010). Just a guy in pajamas? Framing the blogs in mainstream US newspaper coverage (1999 – 2005). *New Media & Society, 12*(2), 271 -288.

Kampourakis, K., & Zogza, V. (2009). Preliminary evolutionary explanations: A basic framework of conceptual change and explanatory coherence in evolution. *Science & Education, 18*(10), 1313 – 1340.

Kerr, A. (2003). Rights and responsibilities in the new genetics era. *Critical Social Policy, 23*(2), 208 - 226.

Kerr, A., Cunningham-Burley, S., & Amos, A. (1998). The new genetics and health: Mobilizing lay expertise. *Public Understanding of Science, 7*(1), 41 - 60.

Khishfe, R. (2012). Relationship between nature of science understanding and

argumentation skills: A role for counterargument and contextual factors. *Journal of Research in Science Teaching, 49*(4), 489 - 514.

Kuhn, D. (1991). *The skills of argument.* Cambridge, England: Cambridge University Press.

Kuhn, D. (1993). Connecting scientific and informal reasoning. *Merrill-Palmer Quarterly, 39*(1), 74 - 103.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77*(3), 319 - 337.

Kuhn, D., Schauble, L., & Garcia-Mila, M. (1992). Cross-domain development of scientific reasoning. *Cognition and Instruction, 9*(4), 285 - 327.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Leask, J., Hooker, C., & King, C. (2010). Media coverage of health issues and how to work more effectively with journalists: A qualitative study. *BMC Public Health, 10,* 535 – 542.

Lenz, L. & Willcox, M.K. (2012). Issue-oriented science: Using socioscientific issues to engage biology students. *The American Biology Teacher, 74*(8), 551 - 556.

Lewis, J., & Kattmann, U. (2004). Traits, genes, particles and information: Re-visiting students' understandings of genetics. *International Journal of Science Education, 26*(2), 195-206.

Lewis, J., & Leach, J. (2006). Discussion of socio-scientific issues: The role of science knowledge. *International Journal of Science Education, 28*(11), 1267 – 1287.

Lewis, J., & Wood-Robinson, C. (2000). Genes, chromosomes, cell division and inheritance-do students see any relationship? *International Journal of Science Education*, 22(2), 177-195.

Linn, M.C. (2000). Designing the knowledge integration environment. *International Journal of Science Education, 22*(8), 781-796.

Marbach-Ad, G. (2001). Attempting to break the code in student comprehension of genetic concepts. *Journal of Biological Education, 35*, 183 – 189.

Marbach-Ad, G., & Stavy, R. (2000). Students' cellular and molecular explanations of genetics phenomena. *Journal of Biological Education, 34*(4), 200-205.

Margoshess, D. (1999, August 20). Saskatchewan farmer battles Monsanto, sues them back. The Vancouver Sun. Retrieved from http://www.grain.org/bio-ipr/?id=275.

Mazur, B.J., & Falco, C. (1989). The development of herbicide resistant crops. *Annual Review of Plant Physiology and Plant Molecular Biology, 40*, 441 – 470.

Means, M. L., & Voss, J. F. (1996). Who reasons well? Two studies of informal reasoning among children of different grade, ability, and knowledge levels. *Cognition and Instruction, 14,* 139 – 178.

Miles, M., & Huberman, A. (1994) *Qualitative data analysis* (2nd Ed). Thousand Oaks: Monton.

Miller, J.D. (2004). Public understanding of, and attitudes toward, scientific research: What we know and what we need to know. *Public Understanding of Science, 13*, 273 – 294.

Mills Shaw, K.R., Van Horne, K., Zhang, H., Boughman, J. (2008). Essay contest reveals misconceptions of high school students in genetic content. *Genetics, 178,* 1157 – 1168.

Mistler-Jackson, M. & Songer, N.B. (2000). Student motivation and internet technology: Are student empowered to learn science? *Journal of Research in Science Teaching, 37*(5), 459 - 479.

Morris, B.J., Crocker, S., Masnick, A.M., Zimmerman, C. (2012). The emergence of scientific reasoning. In H. Kloos, B.J. Morris and J.L. Amaral (Eds.) *Current topics in children's learning and cognition*, (pp. 61 - 82). InTech.

Mysliwiec, T. H., Shibley, I., Dunbar, M.E. (2003). Using newspapers to facilitate learning: Learning activities designed to include current events. *Journal of College Science Teaching, 33*(3), 24 - 28.

National Assessment of Educational Progress [NAEP]. (2006). *Science assessment and item specifications for the 2009 National Assessment of Educational Progress*. Washington, DC: National Assessment Governing Board.

National Center for Education Statistics [NCES]. (2010). Highlights from PISA 2009: Performance of U.S. 15-year-old students in reading, mathematics, and science literacy in an international context. Retrieved from http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2011004

National Human Genome Research Institute [NHGRI]. (2011, May 11). *All about the human genome project (HGP)*. Retrieved from: http://www.genome.gov/10001772.

National Research Council [NRC] (1996). National Science Education Standards. Washington, D.C.: National Academy Press.

National Research Council [NRC] (2001). Stem Cells and the Future of Regenerative Medicine. Washington D.C.: National Academy Press.

National Research Council [NRC]. (2005). *Systems for state science assessments.* Washington, DC: The National Academies Press.

National Research Council [NRC]. (2007). *Taking science to school: Learning and teaching science in grades K-8.* Washington, DC: The National Academies Press.

National Research Council [NRC]. (2011). *Successful k-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics.* Washington DC: National Academies Press.

National Research Council [NRC]. (2012). *A framework for k-12 science education: Practices, crosscutting concepts, and core ideas.* Washington DC: National Academies Press.

National Science Board [NSB] (2000). Science and Engineering Indicators – 2000. Washington D.C.: U.S. Government Printing Office.

Nehm, R.H., & Ha, M. (2011). Item feature effects in evolution assessment. *Journal for Research in Science Teaching, 48*(3), 237 – 256.

Nisbet, M.C., & Scheufele, D.A. (2009). What's next for science communication? Promising directions and lingering distractions. *American Journal of Botany, 96*(10), 1767 – 1778.

Nisbet, M.C., Brossard, D., & Kroepsch, A. (2003). Framing science: The stem cell controversy in an age of press/politics. *Press/Politics, 8*(2), 36 – 70.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*, 994– 1020.

Patton, M. Q. (1990). *Qualitative Evaluation and Research Methods* (2nd Ed.). Newbury Park, CA: Sage Publications, Inc.

Perez-Peña, R. (2009, April 20). The times wins 5 Pulitzer prizes. *The New York Times.* Retrieved from http://www.nytimes.com/2009/04/21/business/media/21pulitzer.html

Perkins, D. N. (1985). Post-primary education has little impact upon informal reasoning. *Journal* of *Educational Psychology, 77*, 563-571.

Perkins, D. N., Farady, M., & Bushey, B. (1991). Everyday reasoning and the roots of intelligence. In J. F. Voss, D. N. Perkins, & J. W. Segal (Eds.), *Informal reasoning and education* (pp. 83 – 105). Hillsdale, NJ: Erlbaum.

Ratcliffe, M. (1999). Evaluation of abilities in interpreting media reports of scientific research. *International Journal of Science Education, 21*(10), 1085 - 1099.

Resnick, L. B. (1987). Learning in school and out. *Educational Researcher, 16*(9), 13-20.

Roberts, D.A. (2007). Scientific literacy / Science literacy. In S.K. Abell & N.G. Lederman (Eds.) *Handbook of research on science education*, (pp. 729 - 780). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Roth, W. M., & Lee, S. (2002). Scientific literacy as collective praxis. *Public Understanding of Science, 11*(1), 33 – 56.

Ryder, J. (2001). Identifying science understanding for functional scientific literacy. *Studies in Science Education, 36,* 1- 44.

Sadler, T. D. (2003). *Informal reasoning regarding socioscientific issues: The influence of morality and content knowledge.* Unpublished doctoral dissertation, University of South Florida, USA.

Sadler, T. D. (2004a). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*(5), 513 – 536.

Sadler, T. D. (2004b). Moral and ethical dimensions of socioscientific decision-making as integral components of scientific literacy. *The Science Educator*, *13*, 39 – 48.

Sadler, T. D., & Donnelly, L. A. (2006). Socioscientific argumentation: The effects of content knowledge and morality. *International Journal of Science Education, 28*(12), 1463 – 1488.

Sadler, T.D. & Fowler, S.R. (2006). A threshold model of content knowledge transfer for socioscientific argumentation. *Science Education, 90,* 986 – 1004.

Sadler, T.D. & Zeidler, D.L. (2005). The significance of content knowledge for informal reasoning regarding socioscientific issues: Applying genetics knowledge to genetic engineering issues. *Science Education, 89,* 71 – 93.

Schauble, L. (1996). The development of scientific reasoning in knowledge-rich contexts. *Developmental Psychology, 32*(1), 102-119.

Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 1-52). Greenwich, CT: Information Age.

Shavelson, R.J. (2008). Reflections on quantitative reasoning: An assessment perspective. In B. L. Madison & L. A. Steen (Eds.), *Calculation vs. context: Quantitative literacy and its implications for teacher education*. Racine, WI: Mathematics Association of America.

Shea, N., & Duncan, R.G. (2010, June). Validation of a learning progression: Relating empirical data to theory. In *K.* Gomez., L. Lyons, & J. Radinsky (Eds.) *Learning in the Disciplines: Proceedings of the 9th International Conference of the Learning Sciences,* Volume 1, 532-539-1039, International Society of the Learning Sciences: Chicago IL.

Shea, N., Duncan, R.G, & Stephenson, S. (2011, April). Exploring genetic literacy: How undergraduate science majors reason about authentic genetic dilemmas. Paper presented at the Annual Meeting of the *National Association of Research on Science Teaching*, Orlando, FL.

Shea, N.A., Duncan, R.G., & Giannetti, L. (2013, April). A content analysis of genetics news articles: Exploring context and content knowledge requirements for genetic literacy. Paper presented at the Annual Meeting of the *National Association of Research on Science Teaching*, Rio Grande, Puerto Rico.

Shimoda, T.A., White, B.Y., & Frederiksen, J.R. (2002). Students' goal orientation in learning inquiry skills with modifiable software advisors. *Science Education, 86*, 244 – 263.

Sky News. (2008, July 17). Brothers are two in a million. *Fox News.* Retrieved from http://news.sky.com/skynews/Home/World-News/Germany-Black-And-White-Twins-Born-To-Mixed-Race-Couple-In-Berlin/Article/200807315041245

Smith, M.K., Wood, W.B., & Knight, J.K. (2008). The genetics concept assessment: A new concept inventory for gauging student understanding of genetics. *CBE Life Sciences Education, 7*(4), 422 – 430.

Stewart, J., Cartier, J. L., & Passmore, P. M. (2005). Developing understanding through model-based inquiry. In M. S. Donovan & J. D. Bransford, J. D. (Eds.), *How Students Learn* (pp. 515-565). Washington D.C.: National Research Council.

The Coolhunting Magazine. (2009). *White is beautiful.* Retrieved from http://5magazine.wordpress.com/2009/09/04/white-is-beautiful/

Thomm, E., & Bromme, R. (2012). "It should at least seem scientific!" Textual features of "scientificness" and their impact on lay assessments of online information. *Science Education, 96*(2), 187 - 211.

Toulmin, S.E. (1958). *The uses of argument.* Cambridge, UK: Cambridge University Press.

Tytler, R., Duggan, S., & Gott, R. (2001). Dimensions of evidence, the public understanding of science and science education. International Journal of Science Education, 23, 815 – 832.

van Mil, M.H.W., Boerwinkel, D.J., & Waarlo, A.J. (2011). Modeling molecular mechanisms: A framework of scientific reasoning to construct molecular-level explanations for cellular behavior. *Science & Education.* First published on: 14 August 2011 (iFirst).

Venville, G., Gribble, S. J., & Donovan, J. (2005). An exploration of young children's understandings of genetics concepts from ontological and epistemological perspectives. *Science Education*, *89*, 614-633.

Venville, G.J., & Treagust, D.F. (1998). Exploring conceptual change in genetics using a multidimensional interpretive framework. *Journal of Research in Science Teaching, 35*(9), 1031 – 1055.

von Aufschnaiter, C., Erduran, S., Osborne, J., Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching, 45*(1), 101 – 131.

Wade, N. (2011a, December 10). Treatment for blood disease is gene therapy landmark. *New York Times.* Retrieved from http://www.nytimes.com/2011/12/11/health/research/hemophilia-b-gene-therapy-breakthrough.html?_r=1&sq=gene&st=nyt&scp=1&pagewanted=print

Wade, N. (2011b, July 4). Roots of disease found to vary by continent. *New York Times.* Retrieved from http://www.nytimes.com/2011/07/05/health/05gene.html?scp=47&sq=genetic&st=nyt

Wade, N. (2011c, June 21). Magnetic field sensed by gene, study shows. *New York Times.* Retrieved from http://www.nytimes.com/2011/06/28/science/28magnet.html?scp=33&sq=gene&st=nyt

Watts, M. & Bentley, D. (1994). Humanizing and feminizing school science: Reviving anthropomorphic and animistic thinking in constructivist science education. *International Journal of Science Education, 16*(1), 83 - 97.

Weible, C., Sabateir, P.A., & Lubell, M. (2004). A comparison of a collaborative and top-down approach to the use of science in policy: Establishing marine protected areas in California. *Policy Studies Journal, 32*(2), 187 - 207.

Wu, T. & Tsai, C. (2007). High school students' informal reasoning on a socio-scientific issue: Qualitative and quantitative analysis. *International Journal of Science Education, 29*(9), 1163 - 1187.

Zeidler, D. L., & Keefer, M. (2003). The role of moral reasoning and the status of socioscientific issues in science education: Philosophical, psychological and pedagogical considerations. In D. L. Zeidler (Ed.), *The role of moral reasoning and discourse on socioscientific issues in science education*. Netherlands: Kluwer.

Zohar, A. & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35 – 62.

Appendix A

Interview Protocol - Study 1

Daily News

Farmer Accused of Appropriating Genetically Modified Corn from Crops Inc.

Yesterday afternoon in a Canadian court room, farmer Bill Brown stood trial against Crops Inc. who accused farmer Brown of patent infringement. Court reporters are saying that farmer Brown has been accused of replanting Weed-Be-Gone corn, a herbicide resistant variety developed by Crops Inc., in his fields without permission from the company.

In a statement made yesterday Brown's lawyer claimed that about the same time that Weed-Be-Gone hit the market last year, Mr. Brown noticed that, "approximately 30% of his 1500 acres were contaminated by the herbicide resistant corn. Many of his neighbors grew Weed-Be-Gone corn in their own fields. But Mr. Brown never intended to grow the corn in his own fields." Being a small-scale farmer, Brown harvested the corn anyway and sold it for profit.

To maximize profits and production, Crops Inc., a Canadian biotechnology company, has developed genetically modified Weed-Be-Gone corn that is resistant to herbicides. These corn plants can be sprayed with herbicides that kill weeds without causing harm to the corn.

The new Weed-Be-Gone Corn was marketed to farmers in Canada and the U.S. with the agreement that yearly licensing fees would be applied in order to protect the company's invention.

Within this agreement it is stated that Canadian patent law allows companies to patent modified genes and insert them into plant varieties, such as corn.

Crops Inc. was later notified about farmer Brown's fields and decided to sue farmer Brown for patent infringement since he failed to pay licensing fees for the corn plants.

In court yesterday, the farmer claimed that he never intentionally planted the Weed-Be- Gone corn in his fields. His defense rested on the idea that gene flow, such as accidental pollination or seed falling from passing trucks, must have been the reason for the presence of the genetically modified corn in his fields.

Crops Inc. responded that gene flow could not have been responsible for the large amount of Weed-Be-Gone found in Brown's field; especially after only having been released for public use in that location eight months prior to the discovery of the corn in Brown's field. They claim Brown planted the corn intentionally.

As of this morning, the jury is still out as to whether or not farmer Brown is guilty of patent infringement.

Recently researchers in the north central U.S. have been randomly testing corn plants from fields meant to contain non-genetically modified crops and are finding increasing numbers of plants that contain modified genes.

A researcher from GM Biotech Labs of Central, Indiana stated in an interview last week with Daily News that "gene flow between genetically modified and natural corn plants is inevitable. In the next 5 to 10 years it is likely that all the corn in the U.S. will, to some degree, contain genes constructed by human hands. Most of these plants will enter our food system without us even knowing it."
Text loosely adapted from Margoshess (1999).

Thank you for agreeing to participate in my study. The information you provide will enhance the field of science education by shedding light on how students think and reason through genetic tasks. Genetic literacy is the primary focus of this study. Today I will be asking you to consider a fabricated genetic dilemma to assess how you use your knowledge of genetics to make a decision. You may not be certain of some of your answers to questions I ask. It is okay to say "I am not sure" but please share your ideas and thinking with me, no matter how inaccurate or incomplete they seem to you. The best way that you can help is to provide your best guesses and to explain in detail your ideas and decisions. If at any time you feel uncomfortable with a question it is okay to not answer.

Interview Protocol: CORN TASK

1. **(Have students read newspaper article to themselves).** Can you describe to me, in your own words, what this story is about?
2. If you were a member of the jury and this information was presented, which way would you be leaning in terms of a decision?
3. What are the key pieces of information in this article you would use when making a decision?
4. If you were a jury member and had access to specific advanced witnesses to help enhance your understanding of this problem, what kind of experts would you like to see on the witness stand?
5. What questions would you want asked of them to help your decision making process?

   At this point, I would like to discuss with you the specific genetic issues involved in this story. This is not a quiz, and it is okay if you aren't sure. Providing your best guess is what's important.

6. **Provide herbicide resistance reading.**
   Can you describe to me in your own words how herbicide resistance works?

PROMPT: provide herbicide resistance paragraph to those experts who are unable to provide an explanation (See separate page – **Have students explain it back in own words**).

7. Can you explain how you think Crops Inc. was able to make the Weed-Be-Gone corn plants? (How does this process work?)
8. Gene flow is the transfer of genes from one population to another. How feasible is it that gene flow could be responsible for what happened in the farmer's fields?
9. If pollination is to blame, how would this result in new corn plants that express the genes for herbicide resistance?
10. Does any of this information change the way you feel about your original decision?

IF CHANGED/UNDECIDED, ASK THE FOLLOWING:

11. What information specifically changed your mind about your original decision?
12. Could you tell me a little bit about your opinions regarding life forms created by genetic engineering?

How does herbicide resistance work?

Most herbicides contain chemicals that target critical pathways in plants. Glyphosphate is an example of a chemical commonly used in herbicides that targets the protein enzyme EPSPS. The EPSPS enzyme is required for synthesis of amino acids-molecules used to make vital proteins that the plant requires for growth. Glyphosphate binds to the EPSPS enzyme and inhibits it from performing its function. Without functional EPSPS the plant dies.

To generate plants that are resistant to Glyphosphate herbicide, scientists introduced mutations in the gene that codes for the EPSPS enzyme. These mutations result in an EPSPS enzyme with an altered structure that is lacking the binding site for the herbicide, yet has a functional active site for the synthesis of amino acids. This altered enzyme is no longer inhibited by the herbicide yet is still able to maintain its function. By doing so, scientists generated corn plants that are resistant to herbicides and can grow while surrounding weeds (or other non-herbicide resistant plants) die.

Text adapted from Mazur & Falco (1989).

Interview Protocol: ALBINISM TASK

1. (**Provide picture A – Af Am albino boy**). Do you know the name of this phenomenon?
2. How is albinism caused? Can you explain what is happening inside the body of someone with this condition?

PROMPT: Do genes have anything to do with it? Do proteins have anything to do with it?

3. Among individuals with albinism, there are different degrees of pigmentation loss. In Type 1 albinism- individuals have loss of all pigment in the hair and skin, Type 2 albinism- individuals have light skin but may have colored hair, freckles or moles, and Type 3 have normal hair and skin but no pigment in their eyes. Can you explain what is the biological basis of these differences?

PROMPT: Can you compare Type 1 and 3, what is going on genetically? For Type 3 people, the gene that is not working in the eye – is it in this skin cells as well? **(get at if they think genes are tissue specific).**

Show picture B and have students read the following paragraph:

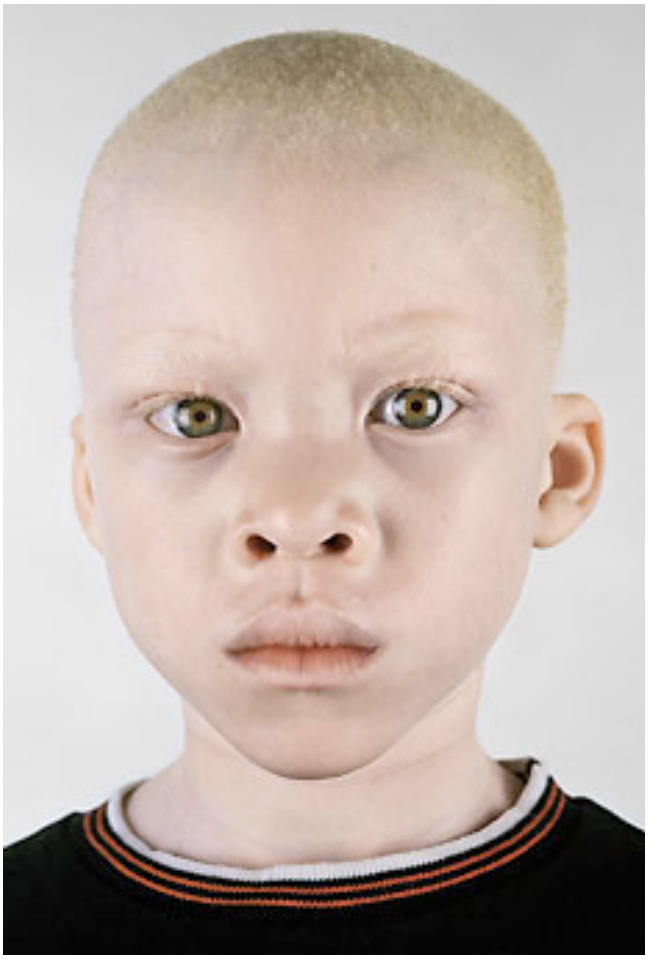
A husband and wife and their five children are seeking the help of a genetic counselor. For the last 7 years the couple has been arguing over whether all the children belong to the husband or to some other man. Two of the five children look very much like their father (who is dark skinned), but the other three are albino. The father argues that the children couldn't possibly be his since albinism does not run in his family line. But the mother insists that a natural, random mutation occurred during their development producing the albino children which definitely belong to her husband and no other man.

4. Can you describe to me, in your own words, what is going on in this reading?
5. After reading this information, whose side are you leaning towards? Why?
6. What evidence would you use to back your opinion?
7. The wife claims that this occurred due to a natural, random mutation that occurred during pregnancy. What does that mean to you?
8. If a random mutation is responsible, how would this occur?
9. Do you think that it is feasible that over half of her children are affected by the same natural, random mutation?
10. Can you think of any other explanations for albinism in this case?

PROMPT: Could it have been in the family line and just never presented itself until now?

11. *** **In response to their answer to question 9:** Can you explain to me how that would work? (**Looking for a meiosis story – albinism is a recessive disorder**)
12. **(Provide picture C – multi-ethnicity family).** This couple gave birth to non-identical twins where one is light skinned and the other is dark skinned. Can you explain what is happening genetically? **(Note: Make sure they understand difference between fraternal and identical).**

Picture A



(The Coolhunting Magazine, 2009)

Picture B

(Jamieson, 2009)

Picture C

(Sky News, 2008)

Appendix B

Genetic Content Knowledge Multiple Choice Assessment

1. Mutations in DNA occur in the genomes of most organisms, including humans. What is the most important result of these mutations?
a. They produce new genes for the individual.
b. They produce new enzymes for the individual.
c. They provide a source of new cells for the individual.
d. They provide a fundamental source of genetic variation for future generations.
e. They produce new chromosomes for future generations.

2. How does the genetic information in a fertilized egg cell (an egg cell that has combined with a sperm cell) compare with the genetic information in the skin cells of the adult organism that develops from the fertilized egg cell?
a. The skin cells in the adult organism contain the same genetic information that was in the fertilized egg cell.
b. The skin cells in the adult organism still contain some of the genetic information that was in the fertilized egg cell, but not very much of the information.
c. Some of the skin cells in the adult organism contain all of the genetic information that was in the fertilized egg cell, but other skin cells contain just a little of the information.
d. None of the skin cells in the adult organism contains any of the genetic information that was in the fertilized egg cell.

3. In sexually reproducing organisms, such as humans, which of the following is TRUE about how many of a son's body cells (any cell in the body except a sex cell) contain DNA from his mother?
a. A little less than 50% of a son's body cells contain some DNA from his mother.
b. 50% of a son's body cells contain some DNA from his mother.
c. A little more than 50% of a son's body cells contain some DNA from his mother.
d.100% of a son's body cells contain some DNA from his mother.

4. Which of the following statements is accurate regarding genetic traits that are determined by multiple genes?
a. Inheritance probabilities of these traits can usually be predicted.
b. These traits are usually controlled by dominant alleles.
c. These traits are usually sex-linked.
d. These traits usually have many phenotypes.

5. Which statement most accurately describes the function of genes?
a. genes control the production of DNA
b. genes control the production of protein
c. genes control cellular movement
d. genes control brain activity

6. Multiple genes are associated with complex diseases such as cancer and mental disorders. When an individual is tested for these genes, what do the results indicate?
a. Whether or not s/he has the disease or disorder.
b. Whether or not s/he has an increased risk for developing the disease or disorder.
c. Whether or not s/he will definitely develop the disease or disorder.
d. Whether or not his/her children will definitely develop the disease or disorder.
e. How severe the disease or disorder will be if the individual has the gene.

7. Molecular genetic engineering is possible
a. because all living organisms have the same DNA sequence.
b.because all living organisms have DNA as their genetic material.
c. because all living organisms have different but compatible structures of DNA.
d. because different genetic materials other than DNA are made compatible by scientists.
e. only among plant species or among animal species, but not between plants and animals.

8. Which of the following does NOT describe genetic diseases?
a. genetic diseases are caused by infectious agents
b. genetic diseases are passed from parents to offspring
c. genetic diseases can be caused by a single gene
d. genetic diseases can remain dormant (hidden) for many years

The nerve cells of a particular animal species contain 20 chromosomes. Use this information to answer the questions 9-12.

9. How many chromosomes would an unfertilized egg cell from this species contain?
a. 0
b. 5
c. 10
d. 20
e. 40

10. How many chromosomes would a fertilized egg cell from this species contain?
a. 0
b. 5
c. 10
d. 20
e. 40

11. How many chromosomes would a skin cell from this species contain?
a. 0
b. 5
c. 10
d. 20
e. 40

12. How many chromosomes does any one individual animal from this species inherit from its father?
a. 0
b. 5
c. 10
d. 20
e. 40

13. Which of the following is unique for every individual human (with the exception of identical twins)?
a. Chromosome number
b. DNA sequence
c. gene sequence
d. protein sequence
e. All of the above

14. Your muscle cells, nerve cells, and blood cells look different because each kind of cell
a. contains different kinds of genes
b. is located in different parts of the body
c. activates different genes
d. contains different numbers of genes
e. has experienced different mutations

15. Rank the following genetic structures in terms of size starting with the largest and going to the smallest: chromosome, gene, genome, nucleotide.
a. genome, chromosome, gene, nucleotide
b. genome, gene, chromosome, nucleotide
c. chromosome, genome, gene, nucleotide
d. chromosome, nucleotide, genome, gene
e. chromosome, nucleotide, gene, genome

The presence of facial freckles in humans is controlled by the expression of one gene with two alleles. The "freckle" allele is dominant to the "no freckle" allele. Use this information to answer the questions 16& 17.

16. Juan and Carolyn both have freckles, but their daughter Katie does not. What does this information indicate?
a. One of the parents carries a "no freckle" allele
b. Each of the parents carries a "no freckle" allele
c. Neither of the parents carry a "no freckle" allele
d. Katie carries at least 1 "freckle" allele
e. There is not enough information provided to make a conclusion

17. If Juan and Carolyn have another child, what is the probability that the child will have freckles?
a. 0%
b. 25%
c. 50%
d. 75%
e. 100%

18. Gene therapy would more likely be successful for conditions caused by
a. a single chromosome
b. a single gene
c. environmental influences
d. multiple chromosomes
e. multiple genes

19. Adult height in humans is at least partially heritable. However, even when environmental conditions are held constant, humans have an extremely wide variety of heights (not just short, medium, and tall). What is the best conclusion that can be drawn from this information?
e. Height is probably influenced by one gene with two alleles.
f. Height is probably influenced by one gene with codominant alleles.
g. Height is probably influenced by genes that affect multiple traits.
h. Height is probably influenced by several genes.

20. An individual is found to have a mutation in a gene associated with breast cancer. In which cells is this form of the gene located?
a. Only in cells of the breast where cancer occurred.

b. Only in cells of both breasts.
c. Only in those cells found in females.
d. Only in the cells of the breast and ovaries.
e. All the cells of the individual.

Appendix C

Interview Protocol - Study 3

Please read the story carefully. Interview questions will follow.

Mr. Oswald, a 32 year old fast food lover, has been struggling with his weight since he graduated high school and moved out of his parents' house. Among his family members, his grandparents on both sides are obese, his parents are not obese, but of his two sons - one is obese and the other is not. Mr. Oswald's wife is also not obese and does not share his love for fast food. Mr. Oswald tried many ways to lose weight with limited success.

Mr. Oswald recently read a news article describing the link between genetics and obesity. At the end of the article was a call for volunteers to provide a DNA sample for a genetics study on obesity. Mr. Oswald submitted his DNA to the study. The researchers scanned his genome and found that he carried a mutated version of the FTO gene ("fat mass and obesity-associated" gene) corresponding to a 45% increased likelihood of obesity. However, the protein produced by the gene was found in very low amounts in his blood.

As part of the study results, Mr. Oswald learned that scientists are still unsure how the FTO gene promotes obesity. However, since the gene is found to be expressed in brain cells, they suspect that it may influence appetite. Recently, scientists discovered that the gene produces a protein that is especially active in brain regions corresponding with metabolism. No gene therapies or drugs are currently available to treat such an issue.

The doctors conducting the study offered genetic counseling to the study participants since, as they stated, genes only partially contribute to health effects. They noted that the percent likelihood of developing a genetic disorder is variable from person to person depending on environmental factors. For example, in a clinical study of twins with the same FTO gene mutation as Mr. Oswald, the doctors found that if one twin was a smoker they were likely to become heavier and have a harder time losing weight than the twin who did not smoke. Therefore, the doctors felt that discussing such environmental factors with genetic counselors may benefit the study participants.

However, Mr. Oswald decided attending such sessions would be a waste of time since he believed that his obesity had more to do with his love for burgers, fries, and ice cream than with a gene mutation. In his personal experience, trying to lose weight over the last half of his life occurred with limited success despite being a non-smoker himself. Therefore, in his opinion, his nutritional choices were controlling his weight and likely that of his family members as well. After all, Mr. Oswald reasoned that he still has a 60% chance of the gene mutation NOT contributing to his obesity and the doctors were still unsure how the gene affected weight gain.

Semi-structured Questions:

1) In your own words, please describe to me what you just read.

2) After reading this story, do you agree more with Mr. Oswald or with the researchers about the link between genetics and obesity? Why/why not?

3) Do any other ideas, not mentioned in the reading, come to mind when thinking about your position?

4) Suppose someone takes a view in opposition to your argument. What evidence could that person cite to contradict your position or to support their opposing position?

5) Why do you think that the geneticists and Mr. Oswald came to different conclusions concerning the effect of a gene mutation on obesity?

6) Is there anything else you would want to know about this issue to support your position?

Now I'm going to ask you a series of questions which relate to the genetics behind the story:

7) General knowledge questions:

- What DNA is? What a gene is? Are they related? Where would you find each?
    - What is a protein?
- Describe to me what is meant by scanning a genome? What is a genome?
- Describe to me what is meant by a mutated version of the FTO gene?
- Describe to me how a mutation could affect a brain cell?
- The scientists believe the FTO gene can influence appetite and metabolism. How do you think this actually works? Do proteins have anything to do with it?
- Mr. Oswald has a low level of the protein in his blood. Would this influence the link between genetics and obesity?
- What does the fact that some of Mr. Oswald's family members are obese tell you about this particular gene mutation?
- Do you think that his obese family members have the same mutation as Mr. Oswald?
- What does it mean to be a "carrier" of the FTO gene mutation?

- What about his children, why is only one son obese and the other is not?

- What do you think it means when the researchers say that a mutation in the FTO gene corresponds with a 45% increase the likelihood of obesity? Mr. Oswald's 60%?

- The doctors mentioned that environmental factors can contribute to a disorder. What kinds of environmental factors would affect weight gain?

    - How do you think smoking might affect weight gain?

- What do you think the doctors meant by "the percent likelihood of developing a genetic disorder is variable from person to person depending on environmental factors"?

- Do you know of any other diseases that have a genetic and environmental link? How are they similar or different from this story?

8) After our discussion, does this change your original position in any way? If so, how?