Summer 2011

Multimodal representation contributes to the complex development of science literacy in a college biology class

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MULTIMODAL REPRESENTATION CONTRIBUTES TO THE COMPLEX DEVELOPMENT OF SCIENCE LITERACY IN A COLLEGE BIOLOGY CLASS

by

William Drew Bennett

An Abstract

Of a thesis submitted in partial fulfillment of the requirements for the Doctor of
Philosophy degree in Science Education in the Graduate College of
The University of Iowa

July 2011

Thesis Supervisor: Professor Brian Hand

This study is an investigation into the science literacy of college genetics students who were given a modified curriculum to address specific teaching and learning problems from a previous class. Improving science literacy has been a consistent goal of science educators and policy makers for over 50 years (DeBoer, 2000). This study uses the conceptualization of Norris and Phillips (2003) in which science literacy can be organized into both the fundamental sense (reading and writing) and the derived sense (experience and knowledge) of science literacy. The fundamental sense of science literacy was investigated in the students' ability to understand and use multimodal representations as part of their homework writing assignments. The derived sense of science literacy was investigated in how well students were able to apply their previous learning to class assessments found in quizzes and exams.

This study uses a mixed-methods correlational design to investigate the relationship that existed between students' writing assignment experiences connected to multimodal representations and their academic performance in classroom assessments. Multimodal representations are pervasive in science literature and communication. These are the figures, diagrams, tables, pictures, mathematical equations, and any other form of content in which scientists and science educators are communicating ideas and concepts to their audience with more than simple text. A focused holistic rubric was designed in this study to score how well students in this class were able to incorporate aspects of multimodality into their writing assignments. Using these scores and factors within the rubric (ex. Number of original modes created) they were correlated with classroom performance scores to determine the strength and direction of the relationship.

Classroom observations of lectures and discussion sections along with personal interviews with students and teaching assistants aided the interpretation of the results.

The results from the study were surprisingly complex to interpret given the background of literature which suggested a strong relationship between multimodal representations and science learning (Lemke, 2000). There were significant positive correlations between student multimodal representations and quiz scores but not exam scores. This study was also confounded by significant differences between sections at the beginning of the study which may have led to learning effects later. The dissimilarity between the tasks of writing during their homework and working on exams may be the reason for no significant correlations with exams.

The power to interpret these results was limited by the number of the participants, the number of modal experiences by the students, and the operationalization of multimodal knowledge through the holistic rubric. These results do show that a relationship does exist between the similar tasks within science writing and quizzes. Students may also gain derived science literacy benefits from modal experiences on distal tasks in exams as well. This study shows that there is still much more research to be known about the interconnectedness of multimodal representational knowledge and use to the development of science literacy.

Abstract Approved: ______________________________
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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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has been approved by the Examining Committee for the thesis requirement for the Doctor of Philosophy degree in Science Education at the July 2011 graduation.

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This chapter provides a summary of the origin and justification for this research study in science literacy. This introduction should orient the reader to the important aspects of the study and how they are connected together. This chapter also describes the research questions which have guided the development of the research methods and analysis to provide the answers which should benefit the research and educational community. Finally, this chapter argues for the significance of this study to the on-going science literacy research which intends to benefit students around the country and the world.

Origin of the Research Study

Improving science literacy has been a consistent goal of science educators and policy makers for over 50 years (DeBoer, 2000). A variety of avenues to pursue educational research has been available during that time for the purposes of improving science education in American (and other) schools from inquiry practices to emphasis on social conditions (Barrow, 2006; Yager, 1998). Perhaps the most far reaching aspects of science education are the practical applications of technology and the possibilities which are available from science literacy. In the aftermath of the Sputnik incident, the push to prepare students to develop their science application knowledge and experience provided clear immediate benefits to the students (and the nation) both economically and strategically (DeBoer, 2000). The other major push was to provide students with improved science literacy which would have broad and far-reaching effects in all aspects of life (*e.g.* democracy) related to science and scientific knowledge (Wolfe, 1970). One of the tenacious problems of all of the interventions and research agendas that have arisen to promote science literacy (which is common among many research programs) is the lack of a clear definition and demarcation of the issues. This study uses the conceptualization of Norris and Phillips (2003) in which science literacy can be organized into both the fundamental sense (reading and writing) and the derived sense (experience and knowledge) of science literacy. These senses of science literacy were then observed in their contexts within this specific science class through the students writing assignments as well as their academic performance found in quizzes and exams. The fundamental sense of science literacy cannot be investigated in its entirety in this study due to the constraints of the research design. However, the principle component of the fundamental sense of science literacy investigated in this study is the students' ability to read, interpret, and implement multimodal representation found in the scientific literature and in their own writing assignments. The multiple modes of representation are the extra-textual components of science literature such as diagrams, graphs, and mathematical equations which allow scientists to communicate their results and ideas effectively.

In a previous college level freshman biology class, instructors identified a lack of improvement in science (genetics) literacy of the key concepts that were taught during the semester. In particular, the instructors identified that a considerable proportion of the students had trouble reading and interpreting research findings and did not change their misconceptions of some genetics concepts towards those accepted by the biology research community. These two problems reflect the two critical components to science literacy, the fundamental and derived senses (Norris & Phillips, 2003). The fundamental sense of science literacy is that the students are able to critique, analyze, comprehend, and interpret the text found in scientific writings or presentations while the derived sense of scientific literacy is the ability of students to understand the underlying themes and unifying concepts found in science community practices. The instructors identified that the students in the prior year's class of Human Genetics in the 21st Century had difficulty interpreting and comprehending the science literature given to them, or the students lacked the rhetorical skills to fully articulate what they had learned from reading the literature. Then, the student's lack of fundamental literacy improvement inhibited the reconciliation of their tenaciously held misconceptions with those accepted as accurate by the genetics research community. As a result, the primary purpose of this research study is to identify the factors which influence the development of science literacy acquisition in the Human Genetics in the 21st Century class.

The instructors of the Human Genetics in the 21st Century class attempted to restructure the course to be more student-centered and accessible to biology non-majors in particular. This shift in curriculum potentially reflected an emphasis on conceptual understanding over content covered as the previous class was very ambitious in the amount of genetics content covered at the expense of depth. In particular, the curriculum was restructured to help address student misconceptions about human genetics as well by directly identifying possible misconceptions or incorrect interpretation during lecture and discussion. As a part of this curriculum restructuring, the homework component of the course included four writing assignments that served as the multimodal representation variable which will be investigated. The use of multiple modes of representation has been found in some contexts to significantly influence science literacy development

(Hand, Gunel, Ulu, 2009). However, there still remains a considerable amount of research to identify how and to what extent multiple modes of representation can improve a student's metacognition and science literacy (Yore & Treagust, 2006). It is argued in this study that the multimodal representation experiences by the students will be associated with some aspects of their fundamental and derived senses of science literacy as it can be measured in this study. The nature and extend to which multiple modes has a functional relationship with the development of science literacy in the restructured Human Genetics in the 21st Century class is the primary research aim to aid in answering the educational problem of improving science literacy in science classrooms. From this study, it is intended to contribute to a growing body of research literature that aims to characterize how science literacy develops through direct observation of classroom behavior and student performance.

Purpose of the Research Study

The current state of research in science education in the United States is showing a considerable focus on improving science literacy as a result of national initiatives such as the Benchmarks for Science Literacy and the National Science Education Standards (AAAS, 1993; NRC, 1996). Science literacy has two major levels of meaning for teachers and science education researchers. At its core, science literacy is the degree of fluency in the scientific terminology, discourse patterns and communication systems used in the scientific community (Norris & Phillips, 2003). However, science literacy also means that students will be able to understand the nature of science, scientific inquiry processes and techniques, key concepts of science, and the relationships among science, technology, mathematics, and society (Hand, Prain, & Yore, 2001). With such a broad array of important components to science literacy, the major problem facing science education researchers is to identify the most efficient and effective pedagogical, curricular, environmental, and administrative conditions for improving the science literacy of our nation's students. When a better understanding of how all of these important components work together to contribute to science literacy, science educators will be able to make more informed decisions for how to address any problems inhibiting optimal science teaching and learning.

In order to contribute to this difficult endeavor, the following research study was performed to investigate the impact of multimodal representation in a restructured college genetics class at the University of Iowa to improve the science literacy of its students. The class, Human Genetics in the 21st Century, was intended to address persistent student misconceptions about genetics by making the content and learning tasks more accessible and comprehensible for the students. As a part of this reorganization, the reading and writing components of class assignments was modified by making at least one multimodal representation a required component of their homework. However, this intention proved more difficult to implement than originally thought and differences between the sections did arise (see Results). This study was originally developed with the intention of providing students in the class the maximum educational benefit with the minimum amount of disruption to their normal classroom activities. This study argues that the inclusion of multiple modes of representation is one possible educational intervention that can achieve this goal.

Modal representation has been found in other science classrooms to improve science literacy (Hand, 2008). Recent research characterizing the nature and effects that multi-modal representation has upon science literacy has become a fruitful avenue for educational research (Hand, Gunel, Ulu, 2009; Jaipal, 2010). This study intends to further expand upon this growing body of literature by helping to identify how multiple modes and which ones aid the learning of genetic concepts as well as the characteristics of the classroom context that influence the students' acquisition of science literacy. The research design and all of the interpretations of the results described in this study are presented for that end.

Research questions

This study was designed to understand how multimodal representation is contributing to student learning in a college level genetic biology classroom. The design of the study complements the research questions due to the nature of the data collected and the degree to which inferences can be made. The context of the study was a cooperative investigation by the instructors of the course along with the principle researcher of this study to determine how the writing assignments of the course are contributing to the learning goals for the students. In order to achieve this goal, a number of research questions were developed to guide the study, data collection, and interpretations of the results. First and foremost is to determine the extent to which the fundamental literacy component of student science writing in the Human Genetics in the 21st Century class, multimodal representation, is related to the derived literacy components of their ability to succeed academically in this course. As a result, the first research question of this study is:

> 1) What is the relationship that is found between multimodal representations in student writing assignments to their academic performance in classroom assessments?

This question makes the first step into investigating the very important issue of promoting science literacy according to the intentions of the class instructors and researcher. However, this question cannot answer all of the important interactions that may exist along with a better understanding of their natural relationship. As a result, another research question was needed to in order to determine if there are significant factors which are contributing to that relationship. The second research question of this study follows as:

> 2) How do the factors which contribute to multimodal representation competency relate to improved classroom performance?

The first two research question will provide enough insight into the learning dynamics of the students in the Human Genetics of the 21st Century class to determine what relationship exists between the two major variables. However, these two questions will not answer all of the inter-actions that will inevitably arise during the course of the study. Any number of unforeseen occurrences may contribute significantly to the students' science literacy or classroom performance. In order to take into account any of these effects, the final research question of this study is:

> 3) Are there any factors outside of the students' classroom writing or assessments which significantly influence, directly or indirectly, their performance?

This research study uses a mixed-methods design of quantitative correlations with qualitative interpretations of classroom observations and interviews to answer these questions from this specific classroom context. Given such an ambitious research agenda of helping to solve the problem of science literacy improvement, these methods will not be sufficient to provide a complete explanation of how science literacy develops, but the purpose of this study is intended to contribute significantly to the understanding of the research problems and provide new avenues of research for future study to the best of the researcher's ability to collect and interpret the data necessary to do so.

Educational Significance of the Study

The purpose of this study is to identify the most important factors influencing science literacy development in a college genetics class while the research questions intend to answer what aspects of the class writing assignments and the classroom environment help improve or inhibit science literacy development. The significance of this study can be found in the research background of understanding of how science literacy develops in science classrooms (Hand, 2008). The current areas of active research which this study intends to contribute towards is examining the dialogic interactions in the classroom as science literacy is developing and the modes of representation which connect the science content to the concepts being actively constructed by the students. With the information gained from this study, it is possible to provide future recommendations for science teachers and science teacher educators for improving their classroom environments to help foster science literacy development.

The nature of this study's purpose is quite broad. The purpose does not focus on any particular aspect of learning, cognitive or social, as being more important than another. As a result, this research study and its methods will not favor one educational extreme over another, but it will include a synthesis of both cognitive and social considerations. Science literacy, the subject of the study, and the focus of the research questions, would demand an interpretative tradition in which to analyze the focus of the research data, written text and modes along with a variety of qualitative data. Analyzing textual data can be done both quantitatively and qualitatively too. Since the research questions include both qualitative and quantitative aims, the methods from both designs should also be incorporated into the study to work synergistically. Finally, student academic performance will be analyzed descriptively and inferentially with the multimodal representation data in order to determine the nature of the relationship between the two.

This study is intended to provide enough interpretive power to allow recommendations to future science education researchers as well as practical applications to science educators. In order to gain as much insight into the intricate relationships that will influence the development of science literacy among the students in this class, a mixed-methods study was used to collect both quantitative and qualitative data. The quantitative data which will be collected will be the student performance on homework assignments and exams. Individual student performance will be correlated between homework assignments and exam scores in order to identify if any significant relationships. Factors which cause changes in student performance will be investigated in-depth using qualitative data analysis. The qualitative data to be collected will consist of classroom observations with voice recording, interviews with teachers and students, a summary survey, and written assignments. The classroom observations, including transcripts, will be analyzed using discourse analysis, the interviews with teachers and students will be analyzed using general qualitative methods. By using all of the data sources and analysis methods described, it will provide a rich description of the relationships that exist in this college genetics classroom which will answer the research questions and contribute to the on-going body of science education research.

CHAPTER II: RESEARCH IN SCIENCE LITERACY

This review of the relevant literature will provide the reader with the necessary background information into the research tradition from which this study arises. This chapter outlines the context of the body of research from which this study arose. It also describes the researcher's bias in terms of the interpretation of science education research and the data which was collected as a part of the study. This chapter provides the conceptual basis for why writing is important to science learning and how multimodal representation in connected to both science literacy and student learning in class.

The State of Science Education Reform

Science education research has a long and rich history from pioneers like John Dewey to pivotal philosophers like Thomas Kuhn to the numerous researchers of science and science teaching today. In addition to the pedigree of science education research is the range of topics and agendas that this research has – from teacher's beliefs to test reliability. Science literacy research covers a wide array of research fields as well; from ontology and epistemology to pedagogy (Yore & Treagust, 2006). Science literacy is important to this study based upon the nature of the research question and the purpose of the study. Science literacy pervades every aspect of learning in the science classroom as students must be able to read and write every day they are in the science classroom in order to learn and succeed.

The writing assignments which were investigated as a part of this study played a key part in the development of the students' learning of the biology content. The curricular changes which were made to the course were intended to address learning deficits that the professor feared would develop if not address preemptively. A key facet of science literacy development is how students learn the science content and where the misconceptions originate that inhibit their conceptual growth. The major curricular change which was made to the homework assignments was the inclusion of a multimodal representation requirement which was intended to force students to think more critically about the content they were reading. It was the intention that this greater depth of thinking by the students would allow any misconceptions to become salient to the student and trigger further inquiry into the conceptual deficits they had. The research literature supports this reasoning due to the cognitive processes that are required for writing and multimodal use as well as the effects of discrepant events to learning (Lemke, 2000; Posner, *et al.*, 1982).

A review of the literature provides an excellent perspective on where student conceptions and misconceptions (sometimes, alternative conceptions) come from and how they can be addressed by science educators (Driver, 1989; Posner, *et al*, 1982). Since there can be no science literacy without literacy, the writing component of the Human Genetics in the 21st Century class composed the primary interest in determining what state students' science literacy can be found in. The importance of writing in science cannot be understated and this literature review can provide only a short overview of a few of the many important aspects of writing in science and science literacy (Yore, Hand, & Prain, 2002). Finally, the inclusion of the multiple modes of representation in the students' writing assignment in this study was revealed as a significant factor in their science literacy development in part of the class due to the representational demands of the science they were exposed to. As science requires modes of representation other than text for science concepts to be communicated, the nature of how modes are used by college genetics students was shown to be valuable for better understanding their conceptual learning (Lemke, 1998). This research paper is intended to contribute to the research literature in science education by characterizing the results from a correlational study of scientific literacy in a college level genetics classroom. The following review of literature provides the background of research which has led to this research study and also provides the necessary framework for interpreting its significance to the science education community.

Science Literacy in Educational Reform

Science education has been the center of national initiatives for many years due to being a perennial target for policy makers and educational reformers in America. The fervor over the state of science education in American schools began after the famous Sputnik incident of 1958. When the Soviets were able to successfully launch the first artificial satellite in orbit before the USA, it sent shock waves throughout the American political and educational communities. An almost unanimous cry for science education reform was made across America. Whether the Soviets were becoming more successful or whether Americans were becoming less successful was secondary to the new anthem that would be repeated to this day: Americans needed to improve science education. One of the major reform drivers was the newly established National Science Foundation. By 1967, the NSF had as many as 67 national initiatives to reform science education (Wolfe, 1970). The intent of the NSF reforms was to help students "think like scientists" and prepare them for future professional careers where they would be in competition with their international counterparts (Duschl, 2008). This type of professional success oriented science education reform was obviously practical in nature.

Some years after the initial science education reforms from the post-Sputnik era, a new wave of science education reforms were started to address the short-comings of the earlier initiatives. From the NSF reforms, the conception of science literacy put a heavy emphasis on students-as-scientists. This caused a focus on what student did not know at the time or could not learn at the time, from a Piagetian standpoint, because teachers and science educators were concerned about identifying and removing obstacles to teaching students to be amateur scientists (Duschl, 2008). There came a slow but steady understanding from the science education community that a content-driven approach to teaching was not reaching the desired learning goals (DeBoer, 2000). A number of different authors began to argue for a wider conceptualization of the problem of raising science education performance in schools (Harms & Yager, 1981). A new wave of reform initiatives began to emerge as a way to broaden the way science educators were defining the problems of science literacy and how to address them (Laughksch, 2000). Unfortunately, all of these calls for redefinitions of the problems also gave rise to a problem in and of itself – the lack of consensus about the nature of science literacy and what to do about the lack thereof in American schools.

Throughout all of the reconceptualizations of the problems within the science education research community, two general goals of science education can be seen in the research. These two main goals have been defined in many ways but can often be seen in the research literature as scientific literacy (conceptual knowledge) and scientific advancement (technological application). Originally, these two goals of science education were not intended to be separated. That is, the conceptual knowledge that students were to be taught was to be directly applicable to their life. One of the first proponents of science education was Charles W. Eliot who said, “An education which does not produce in the pupil the power of applying theory, or putting acquisitions into practice, and of personally using for productive ends his disciplined faculties, is an education which missed its main aim” (DeBoer, 2000, p. 583). In effect, there would be little point to promoting scientific literacy among students if did not enable them to put that knowledge into use in their professional lives which was consistent with the students-as-scientists style of science education reform.

This duality to science education was recently reconceptualized in terms of a fundamental and derived sense of scientific literacy by Norris and Phillips (2003). The fundamental sense of literacy can be easily defined as the ability to read and write science – as well as speaking and listening. However, the fundamental sense has many levels of competency to it. The science literacy that is found in primary school textbooks is far more generalized than those at the secondary level and even more so than at the college level. At the professional level, actual practicing scientists read and write primary literature in science that has a very different focus and intent than textbooks. At their core, primary research publications in journals like the *Journal of Biological Chemistry* are informative, like textbooks, but also contain an aspect of argumentation. The authors of primary scientific literature are writing with the intention of arguing for a certain hypothesis or model to be accepted by the larger scientific community. This persuasiveness is not entirely present in many of the textbook or popular publications that primary, secondary, or even tertiary students read. As a result, there is a graduated difference in the difficulty of the content that students will have to consume as well as changes in the form and function of the rhetorical nature of scientific literature as they progress to higher and higher academic levels. These changes in the scientific literature often create opportunities for students to broaden their conceptual knowledge. However, transitioning to these new levels will also present learning challenges for the students as well. In order for students to attain the higher and higher levels of scientific literacy competency, they must rely more and more upon the fundamental sense of science literacy (Norris & Phillips, 2003). One reason that the fundamental sense of science literacy has not been a crucial focus of previous science education reform movements has been because many students are able to read advanced scientific texts and recall information found therein on quizzes or exams later – often through rote memorization. However, this simple recall of facts does not capture the true fundamental sense of science literacy since these same students had the tendency to paraphrase the content when they were asked to analyze or interpret it (Haas & Flower, 1988). These findings illustrate that there remains more to a fundamental sense of literacy than simply being able to verbalize or memorize a scientific text. Ultimately, if students were to actually *become* scientists themselves, then they would "create, share, and negotiate the meanings of inscriptions—notes, reports, tables, graphs, drawings, diagrams" that are the hallmark of professional science (Anderson, 1999, p. 973). This transition of students from being consumers of scientific text to producers of scientific text is the underlying foundation for the current writing-to-learn movement for science education reform that will continue to expand upon the goals educators have for science literacy (Keys, 1999).

The derived sense of science literacy is less well defined than its fundamental sense. The derived sense of science literacy is mostly considered to include the beneficial effects gained by being scientifically literate in the fundamental sense. Throughout the history of science education, those benefits have ranged from including the ability to compete and promote American advances to society in the world, the ability to prepare students for lives in the workforce, the ability for future voters to be knowledgeable of scientific advances and concerns at levels of government, and the ability of students to be more motivated to learn science and appreciate its influences in modern life (DeBoer, 2000). Most of those definitions of the derived sense of science literacy are "derived" as a result of being able to successfully read and write about the scientific content found within scientific presentations and publications. The content of science includes big ideas and conceptions as well as procedural knowledge about how to use certain scientific equipment or techniques. None of the derived senses of scientific literacy (i.e. scientific competency) would be possible without the fundamental sense. As a result, educational interventions aimed at understanding and promoting fundamental scientific literacy have become of focus of interest in current science education research (Yore & Treagust, 2006). Once a fundamental literacy has been encouraged, students should have better access to the beneficial aspects of the derived sense of science literacy. As Yore, Bisanz, & Hand (2003) have said, "the derived sense subsumes the understanding and application of the big ideas of science in the standards-based definition of science literacy including the unifying concepts of science, the nature of science, the relationships among science, technology, society and environment, the procedures of science, and the social relevance of science." Through the development of the fundamental and derived senses of science literacy, science students today will gain access to all of the important knowledge and qualities that science educators have hoped for their students for over a 50 years.

Education reform through reading and writing interventions has been a major part of the research literature for many years. The importance of understanding the factors which help develop science literacy across many age levels has been a fruitful area of study in recent years (Yore & Treagust, 2006). Many different recommendations for how to improve student writing and learning have also arisen out of these initiatives such as altering the audience the student writes for or encouraging the use of expressive (personal style) writing in assignments or including multiple modes of representation (Hand, Gunel, & Ulu, 2009; Tchudi & Yates, 1983). Perhaps the most basic feature of these writing initiatives has been the claim that writing is a learning tool for students due to the permanence of text that allows students to visualize their thought process for conceptual manipulation that may actually lead to the discovery of new information or concepts (Keys, *et al.*, 1999). Perhaps the major pedagogical issue that is related to science literacy studies has been how to construct "good" writing experiences for students to use when trying to learn their content material. Unfortunately, what constitutes "good" writing is highly dependent upon the writing context (Young & Fulwiler, 1986). As a result, writing in the science classroom may have a very different set of rhetorical demands than writing in a history or health class as well as having different effects based upon the background of the students given those rhetorical demands (Lemke, 2004). This research study aims to identify some of the important rhetorical (e.g. modal) and conceptual (e.g. genetics) factors which are important for the development of the students' science literacy in the context of a Midwestern college classroom.

The current state of science reform initiatives call for an additional round of science education research to further improve the level of understanding of science literacy through various educational experiences (AAAS, 1993; NRC, 1996). These reform goals and initiatives have been a motivating force within the science education research community and have led to numerous research studies which aim to be consistent with them (Olson & Loucks-Horsley, 2000). Of a particular issue has been the number of possible avenues of approach that the science education community has found that may be applicable to solve the problems surrounding how best to implement some of these reforms. A number of conflicts that in-service and pre-service teachers cite as inhibiting these reforms include limitations due to the curriculum (standards), limitations due to time or resources, and limitations due to personal knowledge or experience (Luft, 2001). As a result, these conflicts will have to be addressed at a variety of points in order to achieve adequate implementation of curriculum reform initiatives. As science education progressed, many researchers began to combine different aspects of science literacy with other aspects of the classroom learning experience in order to complement their relationships to new(er) curriculum standards, resource demands, and applications by the teacher in the science classroom (Holliday, Yore, & Alvermann, 1994).

Any educational intervention that is to be successful in a multi-variable environment that is the science classroom will have to be relatively straightforward in its application in order to avoid many of those problems which have plagued educational reform initiatives in the past. The utility of writing as a viable avenue for developing science learning has been established over numerous research studies showing their efficacy (Yore, Bisanz, & Hand, 2003). The problems that science educators then face are trying to narrow down which avenues will allow them to travel the furthest in their circumstances.

Learning in Science Education

One of the primary reasons why the initial science education reforms that arose out of the *Students as Scientists* movement from the post-Sputnik era initiatives was that there was an emphasis on what students did not know. As a result, there came a heavy emphasis upon laying out a detailed curricular roadmap for students to get to a satisfactory level of knowledge that the students will need to be able to do science. Unfortunately, this emphasis of a curriculum destination neglected the curricular origin of the students (Carey, 2000).

The primary motivational force behind the class chosen in this research study was the intention of the instructor to change the course to address student misconceptions. In the previous semester, the professor was dissatisfied by the number of students who returned to prior misconceptions after instruction on the topics had finished. As a result, the professor realized a change in the curriculum would be necessary to achieve his learning goals for the students (see Chapter 3). However, the origin of student misconceptions (or conceptions in general) need to be better understood if educational interventions are to be implemented with success. Science students – indeed, all students – learn their content through an adaptive process where they continually reconstruct their mental representations of concepts to maintain coherency through all of their experiences (von Glasersfeld, 1989). Students do not purposefully choose *not* to learn science content in the way their teaching wants them to. Rather, learning new science concepts for a student is much like water following the path of least resistance. Science students will construct or reconstruct concepts which make sense to them at that given time (Driver, 1989). Without a deep understanding of how students form scientifically accepted conceptions or misconceptions, educational interventions may be totally in vain and not address the underlying issue(s) which is(are) causing the problem(s). The educational theory which will inform the interpretations of this study and the results found therein will be interactive constructivism. This learning theory is able to explain how students form conceptions, misconceptions, or "alternative" conceptions and is based upon two preceding theories of learning, radical and social constructivism.

Constructivism, at its core, claims that knowledge is constructed by learners as a result of their interactions with the natural world in a social and cultural context and is dependent upon their prior conceptions and experiences (Staver, 1998). Although "constructivism" has a rather broad range of interpretation, most constructivists draw heavily upon the works of Jean Piaget and his theories of cognitive childhood development. As a result, concepts such as assimilation, accommodation, and disequilibrium are all part of constructivist vocabulary. The theorist Vygotsky has also been influential, and his "zone of proximity" has been an insightful concept that has also been incorporated into constructivist perspectives (Chaiklin, 2003). Also, Vygotsky's views of how language (which is socially constructed) is used on the part of students to think and write about science (Hohenshell & Hand, 2006). These two theorists with their respective theories have also engendered two distinct interpretations of the basic constructivist position. The first interpretation of constructivism, credited mainly to Piaget, is radical or cognitive constructivism. The second, mainly from Vygotsky, is social constructivism. Afterwards, a third interpretation, which recognizes the arguments made by each, has been called interactive constructivism. An understanding of these three interpretations reveals insights into the nature of learning and the complexities in learning theories (Staver, 1998; Prawat & Floden, 1994).

The most common theoretical background with which most teachers in American schools hold is the positivist perspective. From this perspective, teachers (and students) assume that reality is objective and that it can be objectively measured and understood through reason or logic (Matthews, 2002; Carson, 2005). The primary goal for teaching and learning, then, is for the objective information of reality to be transferred from the teacher to the student (Carson, 2006). This perspective and approach is directly opposed by constructivists who hold an entirely different set of believes. Principally, constructivists would argue that reality may be objective, as it is, but individual learners cannot access that objectivity because each learner is a subjective individual with subjective learning processes (Glasersfeld, 2001). This claim has often been misconstrued by positivists to mean that constructivists are surrealists that deny the existence of an objective reality, but this criticism is entirely uncharacteristic of constructivist theory (Elkind, 2005).

The major implication of the positivist perspective is that students can learn scientific material through direct explanation and that the content they are taught will be transmitted with 100% fidelity. As a result, positivist teaching required little interaction with the students – if at all (Yerrick, Pedersen, & Arnason, 1998). Positivist teaching centers more on didactic lecturing and verification laboratory exercises. If students do not learn the content with 100% fidelity, it is assumed to be the fault of contextual issues (student motivation, low intelligence, etc) other than the nature of learning the science itself (O'Loughlin, 1992). Therefore, if misconceptions from the students do arise – always before instruction begins – then the proper educational intervention for the positivist teacher would be to repeat the content taught and have the student(s) review the content over and over again until it is received with 100% fidelity (Bennett & Park, 2011). Constructivists argue that this is not how learning occurs and is certainly not the proper course of action to take to improve science literacy.

Furthermore, constructivism argues that human knowledge, as well as the methods and standards that are used in inquiry, are all constructed (Phillips, 1995). As a result, the entire bodies of knowledge which humans have created (physics, chemistry, biology, *etc.*) are all constructed knowledge, not just the individual thoughts that a learner holds. In contrast, positivists "do not consider prior knowledge or cognitive structures as a subjective lens through which one views reality" (Carson, 2005). The teacher, then, becomes the primary wielder of knowledge in a positive classroom while neglecting the knowledge background of the students (Staver, 1998). If students in science classes have conceptions which are alternative or indeed, misconceptions, then teachers should become aware of them in order to modify their teaching practices *during* the course. In the case of this study, the professor only became aware of the problems of learning *after* the course was completed from the 2009 semester. At which point, it is too late for the teacher to take any action to help those students.

When the various perspectives of constructivism are considered, differences between them appear to arise in the following questions: What is it that is constructed? Who is constructing it? Where does the construction come from? How is the construction made (Irzik, 2000)? The answers to these questions vary between the perspectives and offer insights into the theoretical underpinnings that each of them possess. A simple, and almost uncontroversial, answer to the first question would be mental representations are constructed by the learner. However, constructivists usually argue that it is knowledge itself which is constructed (Irzik, 2000). The radical constructivist von Glasersfeld said, "Cognition serves the subject's organization of the experiential world, not the discovery of an objective ontological reality (cited in Irzik, 2000, p. 625)." The primary implication of this claim becomes that the knowledge which is constructed by the individual must be internally consistent with their experiences in order to be useful or fruitful (Driver, 1989). The author von Glasersfeld goes on to say that constructivism cannot deal with "truth" in the traditional, positivist sense because the learner does not have access to "truth" as either concepts, ideas, or theories since it is beyond their experiential ability (Irzik, 2000). As a result, the influence of the teacher in a radical constructivist classroom is minimized as it is the student who is in total control of the learning process. However, social constructivist research has shown that the student's learning is influenced by their environment, making the radical interpretation difficult to argue in its pure form (Matthews, 1997).

Social constructivism places much more emphasis on the community of learners and the social environment in which they are learning. The interpretation of this form of constructivism suggests that both teaching and learning are public acts with public material – that is, knowledge is created at the social level (Staves, 1989). Based largely upon the works and theories of Vygotsky, social constructivism makes a strong claim that can be falsified through educational research, and in fact, has been by neoPaigetian researchers who have that children are able to form knowledge of the physical world before they are able to be enculturated (Bereiter, 1994). As a result, an extreme social constructivist perspective seems untenable. However, there is a wide variety of research that does support the role and influence of the culture upon student learning (Bereiter, 1994). Furthermore, the role of consensus among the learning participants is the primary goal of the learning activity. The group members are the ones that define the utility and validity of the concepts that arise, not the teacher (Hand & Prain, 2002). This condition implies a more subjective interpretation of concepts than positivism or even interactive constructivism (see below) that borders on postmodern theory.

The interactive constructivist perspective is an intermediate form of constructivism between the radical and social constructivist claims. Unlike the previous two forms, it does not make a strong or extreme claim to one source or the other for the origin of knowledge but recognizes that both are needed to produce learning. Essentially, when learners are engaged in the environment (or social environment), they construct mental representations and conceptions through individual reflections that give meaning to the experiences (von Glasersfeld, 1989). In this regard, the value of the social influences (other students and the teacher) is recognized without overemphasizing their involvement in the learning process. Essentially, the interactive constructivist perspective advocates that it is the negotiation between the learner and his or her social environment that will produce learning. Negotiation is an important part of the science learning experience (see Chapter 5) and is the characteristic of the interactive constructivist perspective. Negotiation not only occurs between the learner and his or her peers and teacher, but negotiation also occurs between the students' prior conceptions and the content they are learning.

The learning process is thought to be encouraged when the learner expresses their prior knowledge explicitly so that discussion of their conceptual knowledge can reveal paths for conceptual growth or change (Driver & Oldham, 1986). A complementary view of the conceptual process for how this type of interactive constructivism could lead to accommodation (conceptual change) incorporates the negotiation of thoughts and ideas between the teacher or class and the individual learner who struggles to accept an intelligible and plausible concept as fruitful (Posner, *et al.*, 1982). The conceptual change model of learning indicates that student misconceptions or "alternative" conceptions will persist in classrooms even after presentation of the scientific conceptions by the teacher. Only when a disconfirming event triggers dissatisfaction with their current level of conceptual understanding will a student seek a solution to their learning problem. This struggle for understanding is one of negotiation with the student's own conceptual framework and their learning resources: their classmates, teacher, and available content. As a process of this negotiation, students may be able to change their conceptions if they are able to proceed through the steps of the conceptual change model: dissatisfaction, intelligible, plausible, and feasible. During this whole process, the students are constructing new knowledge of the scientific content in a way that is unique to their conceptual ecology. The rich background of science education research indicates that the more pragmatic perspective of interactive constructivism is a much more defensible position of constructivism to hold and the one that will be used to interpret the findings in this research study.

Writing to Learn in Science Education

If writing is to be a central characteristic of science literacy, then a theoretical understanding of the process is useful for data collection and interpretation of this study. Some of the major theories of writing and composition that have influenced science education in recent years have been the works of Bereiter and Scardamalia (1987), Galbraith (1992), and Klein (1999). Although not directly related to science content knowledge or the nature of science, these theories of the writing process are directly related to the learning process of each student as he or she is involved in writing activities in the science classroom. An understanding of the current theories of writing will allow science teacher educators and possibly science teachers as well to help develop learning activities and establish learning environments that can be more conducive to their learning than traditional science classrooms. In this study, the students are asked to complete four writing assignments (see Chapter 3) with unique rhetorical demands as well as a multi-modal representation (see below). These writing assignments may constitute a significant impact on the development of scientific literacy and hence upon the students' learning and, therefore, be properly understood from an educational perspective.

In his review of writing models, Klein (1999) proposes four distinct models that can describe the writing process: point of utterance, forward search, backward search, and genre. All of these models of writing share a cognitive feature that learning is a "goal-directed search through a problem space" (Klein, 1999 p. 211). The main point, then, that separates Klein's models is that writers may select different methods to learn during the writing process, that is, achieve their goals in the problem space. Although studies shown the importance of social contexts upon the writing process (Applebee and Langer, 1987), most of the research in the Writing to Learn field have been with a cognitive psychology perspective. As a result, the main hypotheses proposed by Klein fall within the latter perspective.

The first model proposed by Klein (1999) was the "Shaping at the Point of Utterance" hypothesis that describes how the writer can convert his or her tacit knowledge into explicit knowledge. Klein has argued that this model is immediately accessible to novice writers because it does not employ cognitive strategies that place a high demand upon the writer's working memory. This expressive form of writing is also most similar to natural speech but transcribed into text. However, as Bereiter and Scardamalia (1987) argue (see below), this form of writing will have a limited impact upon the learning of the writer due to the lack of cognitive demand or knowledge manipulation. Although research of writing has shown that new content (i.e. learning) arises during drafting (as well as planning), there has been no evidence to show that expressive writing at the point of utterance leads to conceptual change.

The forward search hypothesis or writing model proposed by Klein emphasizes the discursive nature of writing. Through this model, the writer achieves their writing goal in their problem space by review and revision of their text. Through this iterative process, the writer can develop or create new content and "search forward" toward the writing goal in the process of the composition. Unlike speech, the text itself allows this process to happen due to the permanence of the text on the page which allows for its review and revision.

The backward search model is related to the forward search hypothesis in that the text plays an integral part in the recursive composition of the text. However, in the backward search hypothesis, as proposed by Klein, the writer relies upon goals and subgoals to navigate through the problem space. During composition, the writers will recursively "search back" to determine if those goals have been met satisfactorily. As the writer tries to elaborate their knowledge to satisfy the goals and subgoals, new content can emerge and may lead to transformations within that knowledge. This transformation (also called knowledge-transformation by Bereiter and Scardamalia) may lead to conceptual change as the writer draws upon his or her cognitive strategies and resources to meet the rhetorical demands of the task.

The last model proposed by Klein is the genre hypothesis that separates writing into the different kinds of discourse. Examples of different genres include argumentation, comparison/contrast, explanation, analogy, and personal writing (Klein, 1999). Each genre has its own defining characteristics. The major determinant of a genre is its overall intent while the remaining characteristics support this purpose. New content knowledge has been proposed to arise as the writer attempts to satisfy the discourse elements within the genre and form relationships between their own knowledge and the genre. The sciences have very unique genres of writing that the students will have to negotiate through using their current level of conceptual understanding. The form of a written assignment in a US history class will have a very different form than a scientific laboratory report. However, the actual cognitive process that students must take in order to satisfy the rhetorical goals are not entirely clear from the genre model of writing.

The two models (Knowledge-Telling and Knowledge-Transforming) by Bereiter and Scardamalia (1987) have been briefly described beforehand in the context of writing at the point of utterance and backward search models proposed by Klein. Essentially, knowledge-telling is the same as shaping at the point of utterance. The writing expresses their content knowledge in an expressive form, similar to speech, with no pre-planning or revision in the writing. As a result, no new knowledge or information is created in the writing process, but the writer simply transcribes their knowledge into text. By contrast, the writer that employs knowledge-transforming uses cognitive strategies to solve the rhetorical problem posed and may generate new knowledge in the process of meeting their demands (similar to backwards search by Klein). In order to solve the problem posed to the writer, the writer must move between two cognitive problem spaces: content and rhetoric. By navigating between these two problem spaces, the writer is able to generate new knowledge to satisfy the writing goals specified by the task.

Finally, a writing theory proposed by David Galbraith (1992) is a partial critique of Bereiter and Scardamalia's knowledge-transformation model. Galbraith's model was termed a knowledge-constituting process because he believed that the transformation of knowledge did not produce any new content knowledge but only modified it according to the context of the writing task. In the knowledge-constituting process, Galbraith argues that there is a dialectic between what the writer knows (similar to knowledge space) and what the writer knows rhetorically (similar to the rhetoric space). This process is iterative due to the fact that a writer cannot articulate his or her thoughts of a subject within one sentence – or perhaps even paragraph. So, as the writer struggles to express his or her thoughts in terms of the writing task, the writer will cycle through iterations of their "dispositional dialectic" (Galbraith, 1992 p. 212). As a part of the dispositional dialectic, the writer begins the composition process when he or she may form new connections or alter the strengths of existing connections among his or her units of knowledge. This phenomenon is where Galbraith argues that new knowledge is constituted rather than transformed. New knowledge about the topic at hand can emerge through the dispositional dialectic with the writing task in a way that was not just transformed from one form to another.

These writing theories are helpful when considering the larger context of science literacy research in science education. With a theoretical background of writing, the interpretation of results in a consistent and comprehensible manner is possible. Ideally, interventions for research can be designed with these theoretical models as frameworks or guidelines for the rational, cognitive aspect for written composition.

For the purposes of this investigation, the dialectic from Galbraith's Knowledge-Constitution model will be drawn from most heavily along with the genre model from Klein. In particular, the conditions which influence the length of the dialectic in Galbraith's model directly tie to this study. A number of factors determine how many local cycles the student will need to satisfy the rhetorical goal of the genre. The major factors which will cause a longer dialectic for the student when writing are the complexity of their disposition, the range of ideas and knowledge that gets activated by the rhetorical demands, the writer's range of rhetorical knowledge (genre specific), the complexity of planning and revision for their writing, the purpose of the written composition (also related to genre), and the form of the writing output (Galbraith, 1992). The form of the writing output is very important to this research study since most scientific literature is composed of more than text. In fact, scientific writing is composed of figures, diagrams, mathematical equations, tables, and more. All of these extra-textual features to student writing will make the form of their output far more complex than simply text. To be scientifically literate, the students in this study will necessarily have to go through longer periods of the dispositional dialectic in order to successfully meet their conceptual and rhetorical goals.

Multimodal Representation in Science Literacy

Science, like most careers, is a social institution carried out by trained, professionals. Because science is not a solitary endeavor, its participants have to communicate with one another on a regular basis in order to contribute to its progression. Scientists must work together cooperatively while performing research and must communicate their findings to one another to publish their results or to compete for additional funding. Communication among scientists is such a pivotal part of the entire institution that the argument has been made that science is impossible without a central role for language (Hand, Gunel, & Ulu, 2009). From formal research presentations at professional meetings to very informal, laboratory meetings among co-workers, scientists use language in very specific and constructive ways. Scientists use their language to explain and construe meaning from their work in order to make sense of their scientific results in the context of what is known about life, chemistry, and physics. This dependency on language is the foundation for the fundamental (and indirectly the derived sense) of literacy as described by Norris & Phillips (2003) discussed above.

In the process of conceptualizing and communicating their ideas and findings, scientists must be able to use a variety of methods to articulate their understanding. In professional settings, scientists must use figures, graphs, diagrams, mathematical equations, and even non-verbal gestures when giving personal accounts of their scientific ideas and findings. All of these methods of representing ideas and concepts are different modes of representation. In the overall course of scientific discourse (formal and informal), these multiple modes of representation are just as prevalent to the professional process of communication, collaboration, and competition as written text. In fact, in any professional science publication (Science, Nature, etc.) or textbook, readers will be inundated with figures, graphs, tables, and all manner of modal representations. Just as scientists represent ideas and discoveries in modes other than text to communicate with others so, also, do science students learn about those ideas and discoveries using the same forms of representation. As students become enculturated into these same forms of communication, they must learn to be fluent in them if they are to be successful in the science classroom and beyond (Lemke, 2000).

The importance of representing scientific concepts in multiple modes to the process of science means that it must necessarily be an important consideration for science educators as well. When students are faced with learning the same ideas, concepts, and reported scientific findings that the professional researchers learned, they will also be exposed to the same or similar modes of representation that were used originally. In some instances, it may be not possible to separate a scientific concept from its mode of representation. Several proposed theories and models are represented by figures, graphs, diagrams, etc. and are not communicated without them. From the structure of DNA in biology to chemical reactions in organic chemistry, the modes of representation that are used to communicate the concepts become a part of the language of science. Therefore, science students will then be faced with the challenges associated with learning the language of science along with its modes of representation, and science educators will need to consider the process of student learning of multi-modal representation. The next step for science education researchers is to investigate the link between the multiple modes of representation in science and learning in science literacy.

Connections between the Literature and the Study

The question that science education research must then answer is: how is multi-modal representation connected to science literacy? To answer this question, science education researchers must begin by looking at how students (and scientists themselves) are able to integrate and coordinate the multiple modes of representation in their investigation and conceptualization processes. In science literature and science textbooks, there is no division between text with graphs and text with equations. All of the science material is presented in a mixture of modes working together as one comprehensible, coherent language (Jewitt, *et al*., 2001). For students learning in science, these multiple modes of representation place a high demand on their cognitive processes as Lemke (2000) states, "What it means to be able to use a scientific concept, and therefore to understand it in the way that a scientist does, is to be able to fluently juggle with its verbal, mathematical, and visual/graphical aspects, applying whichever is most appropriate in the moment and freely translating back and forth among them." This ability for students to "translate" the concept across modes is perhaps the hallmark of student *understanding* of science concepts – rather than rote memorization of a finite instance of its use. When students understand the limitations and implications of each mode that can be used, it indicates a critical step in the development of the student's science literacy skills (Jewitt, *et al.*, 2001).

With the introduction of a vast array of modes, each unique in their own way, to communicate the concepts of science, there arises the possibility that the modes used to represent the concept will not be necessary or sufficient to capture its complete meaning or the specific meaning intended by the writer (Jewitt, *et al*, 2001). Major concepts encompass more than a single thought and many scientific hypotheses, theories, or laws possess complex relationships which cannot be summarized with only one mode (ex population genetics). Therefore, if scientists and students are to fully articulate the concept – either for distribution or assessment – then out of necessity, more than one mode will be required to convey that information. The modes scientists use are not even restricted to written modes but also include verbal and non-verbal expressions (Lemke, 1998). Multimodal representation in science truly encompasses the entire educational experience that science students can participate in.

Students must integrate the numerous modes of representation seen in science literature or in the science curriculum in order to develop a coherent understanding of science concepts. Conversely, students may use the writing composition process in which he or she chooses modes in their writing process to express their knowledge and even help them constitute new knowledge which is coherent with those modes (Galbraith, 1992; Prain, Tytler, & Peterson, 2009). During a science class, students might be listening to a professor lecturing about a concept (e.g. ideal gas law) while looking at an equation on the blackboard and back again at a graph in their textbook illustrating a relationship between the variables. During this short snapshot into a typical science classroom, students are consuming a number of different modes almost simultaneously into a single cohesive concept. Due to the demands of having many different types of modes that the students will be required to process, if the students have any difficulty in assimilating the information from that particular mode, then it is likely that they will develop either a partial or flawed interpretation of that concept. When students gain the competency to use multiple modes in their correct purpose, it may compose an important learning milestone for the student (diSessa, 2004).

It could be possible that a given instance of a student not understanding a particular modal use will lead the student(s) to investigate that particular modal use in relation to that concept in greater depth. This informal, investigation by the student may actually constitute a legitimate inquiry by the student if pursued shortly after that instance. By investigating the relationship between that modal usage and the overall concept, the student will be actively learning about the concept in such a way as to form new or stronger connections within or between concepts (Prain & Waldrip, 2006). The extreme form of this type of investigation would be an accommodation (in the Piagetian sense) of the students' ideas as he or she struggles to translate the mode into an understandable form. The student may be faced with a particular diagram, graph, etc. that is so dissimilar or discrepant from what they have seen before that they are forced to reconsider their prior conceptions of the topic. More likely, when students reconsider their prior conceptions, they will form new connections and/or add to their previous experiences that will allow them to think and communicate about the content more clearly (Carolan, Prain, & Waldrip, 2008; Prain, Tytler, & Peterson, 2009).

The interpretation and translation of modes of representation by students can occur in both directions – from consumption to production. During course assignments, students will be required to produce their own modes of representation as a part of classroom assignments, homework assignments, and assessments in order to express their understanding of the science concepts. Similar processes will be used cognitively by the student when producing his or her own instance of a multi-modal representation in that they will need to articulate their ideas and understanding of the concept by translating it into a new form (Prain, Tytler, & Peterson, 2009). However, the student will be faced with a similar dilemma as the scientist or author who needs to consider the important aspect of the content and decide which mode is most appropriate in order to effectively communicate their ideas as well (Yore, Hand, & Florence, 2004). Namely, students will have difficulty to completely expressing the entire scope of their conceptions with only one mode of representation at a time (Carolan, Prain, & Waldrip, 2008). This insufficiency of representation is a by-product of the complexity of concepts that are typically found within the sciences. The larger and more complex the concept, the more text and/or modes the students will have to be used in order to fully express their understanding.

This problem of expression was described above by the Knowledge Constitution model of writing as one that is characteristic of the writing composition process (Galbraith, 1999). If multiple modes of expression are seen as competency in different “languages” of science or perhaps “dialects” within the language of science, then the process whereby students activate idea units in relation to the main concept will be an extension of the Knowledge Constitution model. As described above, the Knowledge Constitution model posits that idea units are activated when the student considers the concept in his or her mind. As the student begins to write text or, in this case, compose the modes, additional idea units are activated that related to the specifics of what is being expressed. As that information becomes permanently displayed on the page, those idea units feed back on the process to inhibit those units just expressed. So, the student may be writing a chemical equation or drawing a biological diagram, and as he or she is composing those modes, that information is feeding back into their composition process. This inhibition allows subsequent information that is less powerfully connected to the concept to become activated. As the student continues composing their paper (with text and modes), he or she will progress through a number of cycles of activation, composition, inhibition, and alternate activation until the student reaches a point of sufficient inhibition for the entire concept in their conceptual framework. Since the student is expressing his or her understanding of the concept in new or alternate ways in order to satisfy the rhetorical demands of the writing task, then they may constitute new knowledge as that information is translated into a new mode (graph, diagram, table, etc.) from the organization that information was in originally.

This knowledge constitution of a science concept using multiple modes of representation is the critical point at which multiple modes of representation intersect with science literacy. The student who is reading a science journal or textbook will constitute the information they see into their knowledge network. Likewise, when students are asked to produce a written product for a class assignment, they may constitute new knowledge as part of the writing constitution process when incorporating multiple representations. Students must not only understand and interpret content within a modal representation but must also be able to translate between modes when synthesizing a written composition (Hand, Gunel, & Ulu, 2009). Translating within and between modal representations when writing will place a far more complex disposition upon the students than simply text and will lead to many more cycles within their dialectic before reaching their rhetoric goal. With a much longer and complex dialectic that the student must negotiate through as he or she is writing, there will be a far greater opportunity for him or her to constitute new knowledge through the use of their multi-modal representations (Galbraith, 1992).

The next question that faces science education researchers is whether multiple modes of representation that have the capacity to enhance student learning have actually been found to be associated with science students' conceptual growth or change. In a relatively early study of student and teacher use of multi-modal representation in learning science, primary students in Australia were found to be able to give more accurate accounts of learning the relevant content by linking their understanding across the different modes of representation. However, students who did not recognize any conceptual link between the modes did not translate their understanding across different types of modal-representation (Prain & Waldrip, 2006). This study showed that students who recognize the conceptual link between different modes of the same concept are able to articulate a much fuller understanding of the science concept. Conversely though, teachers in that particular study did not teach their students about the explicit conceptual connections across the modes or use them significantly as an assessment strategy. As a result, fewer links between multiple modes were made than probably could have if more of the teachers' scaffolding had been provided (Prain & Waldrip, 2006).

Science content knowledge is not the only aspect of science literacy that multi-modal representation overlaps with. In order to communicate in science using modal representation, the writer (and students) must have a good grasp of the rhetorical task and the strategies needed to satisfy it. In a university study using biology students, it was found that inexperienced ecology students failed to communicate clearly and consistently in class using interpretations of graphs about populations of animals (Bowen, Roth, & McGinn, 1999). Compared with professional scientists who could accurately communicate with one another during discussions about interpreting population graphs, students experimented with using ambiguous definitions and terms. This ambiguity in communication caused problems among the students when they tried to negotiate within the group about the meanings of the graphs. Even with their vague vocabulary, the students were able to answer questions correctly in class related to interpreting content within graphs. However, the students relied heavily upon previous examples scaffolded by the teachers and were found not to have significantly increased their understanding of the ecology content as a function of interpreting the graphs. This finding is troubling for implications to include multi-modal representations as a part of classroom curriculum. It indicates that simply exposing students to multi-modal representation rhetorical tasks may not be a sufficient bridge to reach the expert level scientific literacy commanded by actual scientists. During this study, an interesting distinction became known for why students and scientists interpreted the ecology graphs differently. The students were motivated to answer questions related to the graphs based upon an external motivation to do well on an upcoming examination whereas the scientists were drawing upon personal knowledge from actual investigations in science that came from internal motivation. This different in motivation was found to be important because the students approached solving the graphical problems in an analytical approach that was not related to the concepts in the course whereas the scientists were applying their knowledge from experience in legitimate inquiries in the content domain and were therefore able to provide more interpretations of the graph that were grounded in science content knowledge (Bowen, Roth, & McGinn, 1999).

An interesting outcome in multi-modal representation research that is indirectly tied to student learning is its effect on student motivation in some circumstances as well. A study that asked students to focus on key concepts through representations and *re-representations* found that students were more motivated to learn the material than traditional students (Carolan, Prain, & Waldrip, 2008). One of the key interventions in this study was the repetition of representation that the students were asked to perform. Repeated exposure not only allows for additional time on task but practice with the content and practice with the modes of representation. This finding supports an earlier work in multi-modal representation that focused on the assessments of which modes were used in conjunction with representing the underlying concept. Middle school students were found to perform better in science if they understood that no single modal representation will be able to encompass the entire concept. So, those students tried to only include modal representations that were clear, unambiguous, gave minimal but sufficient information, and were comprehensive to its rhetorical purpose (diSessa, 2004).

In contrast, students who did not perform as well lacked an adequate understanding of when and where to use certain modes to clearly communicate their understanding. Essentially, those students who struggled with the concepts and rhetorical tasks needed more practice and scaffolding by the teacher to be competent in the area, or meta-representational competence. This competence could also be reconceptualized to mean that students who have a greater repertoire of modal representation are more "fluent" in the language of their science. That is, students with a broad meta-representational competence are able to read and write science more accurately and sufficiently than without that expertise. In effect, the students with deep multi-modal representational knowledge of science concepts are more scientifically literate.

Significance of the Literature to the Research Study

The tradition of education and science education research has provided a rich background in which this study will be conducted. Previous research studies have identified why interactional constructivism is important when informing the development of student-centered classrooms (Prawat & Floden, 1994; Simon, 1995). The development and maintenance of alternative (misconceptions) in science classrooms has been shown to be a significant hurdle that science educators must overcome to improve the development of science literacy (Driver, *et al.*, 1994; Posner, Strike, & Hewson, 1982). By considering the influences of the classroom environment upon student-centered learning, the importance of the classroom context can also be seen on the development of science literacy (Yoon, Bennett, & Aguirre-Mendez, 2010). Also, the cognitive processes that describe how students compose their written assignments will also yield valuable insights into the learning process that will occur in this proposed research study (Galbraith, 1992; Klein, 1999). Finally, previous studies have outlined the importance of multiple modes of representation in developing science literacy (diSessa, 2004; Hand, Gunel, Ulu, 2009). Taken together, these previous studies form a foundation upon which the research data collected in this study may be interpreted in a meaningful and significant manner for the current avenues of science education research today.

This research study is intended to expand upon the scientific body of knowledge that has been previously reported. This study focuses on the development of scientific literacy in a college biology classroom that has undergone curricular changes to prevent tenacious student misconceptions. The introduction of multi-modal representation tasks within their course homework may lead to conceptual growth or change within the students. This research study will provide further insight into the avenues of fundamental and derived literacy that will aid science researchers and educators in the future to refine science curricula to provide the better educational experiences for science students tomorrow.

CHAPTER III: RESEARCHING MULTIMODAL REPRESENTATIONS

This chapter provides an explanation of the research design of the study as well as the methods of analysis of the research data collected. This study is a mixed-methods correlational design intended to investigate the relationships between multimodal representation and academic performance within a college genetics class. These two variables relate to the fundamental and derived senses of science literacy but make no attempt to total encompass all aspects of the fundamental and derived senses of literacy. This study is bounded by the limitations of the research design and its subsequent ability to interpret the interactions within the science literacy development of the student participants.

Methodological framework of the research

A mixed-methods approach is founded in educational pragmatism which has developed since its proposal by Dewey nearly 100 years ago (Johnson & Onwuegbuzie, 2004). This research design is correlational in terms of its quantitative data analysis but also qualitative as well. The combination of the two data collection traditions is what constitutes the mixed-methods approach. Both types of data analysis are intended to provide as much descriptive power as possible about the educational phenomena that were observed during the study. This approach is pragmatic because it is argued no single research tradition or data set will be capable to describing or explaining all aspects of an educational phenomenon. The quantitative data analysis of this study focuses on the inferential tests using correlational data but also includes other quantitative results such as student's t-tests from descriptive data. The quantitative data analysis in this study will only describe the degree of the relationship between the variables of student performance and will not presume causality. Causality can only be claimed by other research designs such as a strong experimental design. Neither quantitative nor qualitative educational research methods are designed to answer the research questions separately but function synergistically to provide as rich of a description of the relationships as possible.

Research Design of the Study

This study used correlational data to find relationships between multimodal representational knowledge and the academic performance and a variety of associated factors. However, a strong experimental design is the most powerful in determining the effect a variable has in an educational intervention. A strong experimental design, or even a quasi-experimental design, would not have been possible given the constraints on this study. As a result, a mixed-methods correlational research design was chosen due to the request for limited interference by the professor of the Human Genetics in the 21^{st} Century course. Since the college student participants were responsible for class registration, a strong experimental design with random assignment was not possible. Self-registration also had significance for the composition of the participant pool and their characteristics (see below). If a similar experiment were performed in a secondary or elementary school setting in which the administration had some control over enrollment, then a strong experimental study could have been performed with random assignment into either a control or experimental group section. Also, the professor, Mr.

Matthews, believed that a quasi-experimental design in which only one section received a designated number of multimodal representation requirements as part of their writing assignment would be unethical due to the difference in workloads between sections. Even if student assignments were attempted to be equalized by adding another non-modal factor to a writing assignment (additional reflection or summarization for example) so that workloads were more equal, the professor preferred not to have only one section receive only one kind of treatment. His reasoning - supported by the researcher - for equality between sections was to avoid purposefully providing only one section with a treatment that may benefit the students of one section more than another. Even if the science education research literature could not provide strong evidence that one section would receive better treatment than the other, the perception that one section might receive better treatment was enough of a difference in research design that the professor, Mr. Matthews, preferred not to allow this study to proceed with his approval as a quasi-experimental study. Due to these restrictions, a mixed-methods correlational design allowed for an investigation into the relationship between multimodal representation and academic performance without compromising any ethical considerations.

This mixed-methods correlational research design examines the student participants based upon their performance by the research question variables: classroom academic performance and multimodal representations. Since there was no random sampling or assignment of the participants into groups, both sections of students were given the same classroom conditions. The only exceptions to the equity between sections were the instructional differences from having two different teaching assistants and counterbalancing of the writing assignments.

All students were given four writing assignments in which they were required to include at least one example of multimodal representation of science concept(s) in order to accomplish their writing task. However, each section was given a slightly different set of writing assignment instructions for each homework assignment: reflective, inquiry, comparison and contrast, and persuasive argument (Appendix A). The writing assignment instructions were alternated between sections. Section 1 received the same instructions for their second writing assignment as Section 2 received for their first writing assignment and vice versa. The counterbalancing of the writing assignment instructions was intended to minimize any effect the specific rhetorical tasks may have contributed to class performance on the following quiz or exam. This counterbalancing is not part of an experimental design with a control group and an experimental group, but it is a correlational design because the study will determine the degree of the relationship between student academic performance and the degree of the students' representational knowledge without deference to specific writing assignment rhetorical tasks. The overall purpose of this study focuses on any differences in academic performance or science literacy that are found between students who have various degrees of implementation of their educational multimodal representation knowledge.

In order to gain a rich understanding of the context of the student's learning, qualitative data was needed to assist in answering the research questions. Qualitative research methods and data reveal important characteristics about the personal learning experiences of the students and the classroom environment in complimentary ways to the correlational data. The analysis of the data was concurrent with the data collection for the purposes of identifying emerging concepts from the data (Dey, 1999). All of the research data, quantitative and qualitative, was collected and analyzed throughout the duration of the study to describe and explain the progress of student science literacy learning.

Classroom Characteristics of the Study

The Human Genetics in the 21st Century class was a college level genetics class for non-majors and majors at a major Mid-Western University. The classroom environment of the study included the all aspects of the context of this research which includes the university, the students, the teachers, and even the presence of the researcher. This genetics class is a freshman-sophomore level biology class for non-major students that satisfies general elective requirements. Although many biology majors may take this course, there is another genetics course offered at the same university for biology majors only. This other advanced genetics class is often required for many biology programs. As a result, relatively few biology majors enroll for this course since they are required to take the other genetics class. Regardless, the context of this investigation should approximate a typical Mid-Western college science classroom in terms of the positionality and number of the students participating in it. The numbers of research participants in this study were 36 with 3 instructors (one professor and two teaching assignments). There were two guest lecturers who were professors at the same university, but neither of these lecturers participated in interviews. There were 11 male and 25 female student participants. The ethnic background of the class included 2 East Asian students, 1 Indian student, 1 Hispanic student, and 32 Caucasian students. There were only 6 biology majors students , 25 non-majors students from various programs such as science education or nursing, and 5 students who had undeclared majors at the time of the study. The teaching assistant for section 1 students was a Caucasian male, science education graduate student while the teaching assistant for section 2 was a Caucasian female, biology graduate student. The professor of the course was a Caucasian male from the department of biology. The researcher of the study was a Caucasian male in a science education graduate program.

Research Data Collection

Writing assignments were collected from the instructors prior to grading for qualitative analysis, but all student grades from writing assignments, quizzes, and exams were recorded in order to describe and infer differences based upon the educational conditions in the classroom. Personal interviews with students or teachers were scheduled at the end of the semester after all coursework had been completed. Interviews and writing assignments were the basis for subsequent qualitative data analysis.

Development of a focused holistic rubric

All of the writing assignments were assessed for representational knowledge and use through a focused holistic rubric constructed for this study by the researcher (Table 1). A focused holistic rubric is an educational method that allows the researcher to classify observations into levels based upon defining criteria (Mertler, 2001). In general, a focused holistic rubric is intended to capture the overall student performance in a specific academic area without breaking down their performance into constituent parts. Conversely, an analytic rubric is one in which the teacher scores those constituent parts

Table 1: Focused Holistic Multimodal Representation Grading Rubric

Domain	Representational
Purpose	Describes how well students use alternative modes to express their knowledge or claims
0	No modes but text; the modes in source material are not described
1	One alternative mode used; not embedded; source modes not described fully; not coherent/connected; mode is unoriginal*
2	At least one multimodal use embedded; embedded away from relevant text (or mode not completely appropriate/coherent); source modes identified but not explained; modes not completely original or unoriginal
3	At least one multimodal use embedded; embedded next to relevant text and explained (mostly coherent); source modes explained; modes are completely original
4	More than one multimodal use embedded; embedded next to relevant text and completely explained in relation to the concept; source modes explained in relation to the concepts; modes are completely original with creativity/novelty

Note: *If points are split evenly between levels, consider the overall quality of the mode supporting their conceptual claims.

for inclusion or performance (Did the student do it? Yes? Check) and then add those scores to make a total score. Neither of these types of rubrics should be confused with a simple check-list of student performance. In both cases, the teacher (or assessor) must interpret the student performance to a certain degree. As opposed to the other two rubric types, the focused holistic rubric was used because it can tolerate a higher level of inference by the user that is needed to than the analytic rubric. This type of holistic rubric is especially useful when there is no single correct answer to the students' performance. Mertler (2001) defines the focus of a focused holistic rubric as the overall quality, proficiency, or understanding of the specific content and skills – it involves assessment on a one dimensional level. The focused holistic rubric in this study was designed to capture the extent of the knowledge of representation that students had within science literacy. Therefore, the levels of distinction were created in order to distinguish between those defining characteristics of increased knowledge in the form of scientific representation.

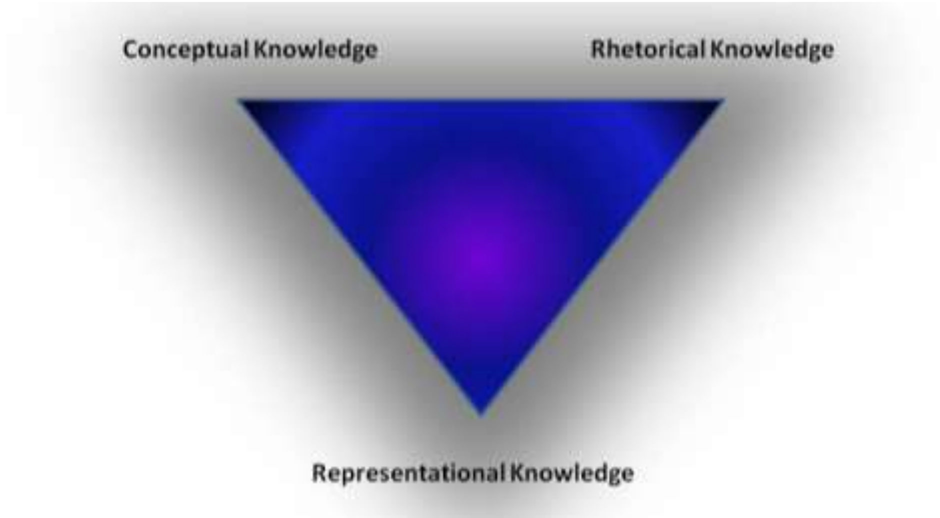
The rubric was used as a guideline for describing, not defining, the characteristics of each level. The focused holistic rubric scores range from 0 to 4 with zero indicating the lowest level of representation, none at all, to 4, indicating the maximum level expected for a college biology student. The level of representation for all students in other classes, particularly in secondary or primary schools, may have levels which correspond to different level of representation knowledge. Likewise, professional scientists are able to generate representations at a level higher than level 4 in this rubric. However, the levels of this rubric correspond to those which were used by the students in this study. Difficulties arose during the development of the rubric when student papers had characteristics of multiple levels. The descriptive characteristics in the rubric were refined through multiple revision cycles with two additional science education researchers. When the revisions were not capable of being able to reliably assign one level to a student's paper using only the characteristics within a level, then assessors would use whichever level had the most characteristics which described the paper's level of representational knowledge use the best.

The focused holistic rubric was developed over the course of the study through numerous versions to identify the most appropriate measure of multimodal representation knowledge for this specific class. This rubric was not designed to encompass all multimodal representational knowledge use in all educational settings. A number of characteristics emerged from the data that were indicative of improved science writing – or conversely, immature scientific writing. The first, and most obvious, characteristic of representational knowledge is whether or not a multiple mode is actually used in the writing at all. However, once more than one mode was used in a writing sample, the problem of generalizing the students' overall representational knowledge became problematic. These problems were the focus of numerous revisions between the researcher and additional educational researchers who assisted in the refinement of the data analysis. The rubric was also developed through the assistance of two additional science educators through numerous revisions to develop the number and content of the level characteristics during the course of the study. After the rubric reached a level of consensus, 10% of the papers were used to determine the inter-rater reliability which yielded an 80% agreement. Although not low enough to merit an alternative rubric design, the inter-rater reliability does support the fact that this style of rubric uses assessor inference to assign MMR levels.

In addition to representations of scientific literacy, the focused holistic rubric also encompassed rhetorical knowledge and conceptual knowledge through its grading of multimodal representation. Rhetorical knowledge and conceptual knowledge are closely related to representational knowledge since both domains must be present in order for students to understand and use scientific representations. Students must have knowledge of the rhetorical domain standards and conventions within science literacy in order to be able to read and write science in the fundamental sense. Also, rhetorical knowledge becomes important for students as they are reading or writing science because all representations in science (figures, graphs, diagrams, etc) must be used in their appropriate context to be intelligible for the audience. Likewise, there are no representations without content and concepts that are contained within those representations. This close association with rhetoric and concepts makes the task of separating these domains extremely difficult. In fact, representation could be considered as a continuation of both rhetorical and conceptual knowledge rather than a totally distinct domain of knowledge. Using a conceptualization of representation in this manner, the writing process which incorporates modal representation may lay on a spectrum between conceptual knowledge and rhetorical knowledge. As a result, the focused holistic rubric that was developed to assess students' skill in using multiple modes was intended to measure those aspects of the writing composition process that lay as far to the point of the representational end of the science writing triangle as possible (Figure 1).

The other primary quantitative data was collected through the teaching assistants and the professor. The other sources of data which are used in this study include the quiz and exam scores of each student. The entire quizzes were collected from the anonymous students and allowed for document analysis. However, entire exams were unable to be collected from the professor of each individual student. Instead, only the names and total scores of the student were collected. Item level responses by the students on their exams were not included in this study.

Figure 1: Connections among Multimodal, Rhetorical, and Conceptual Knowledge

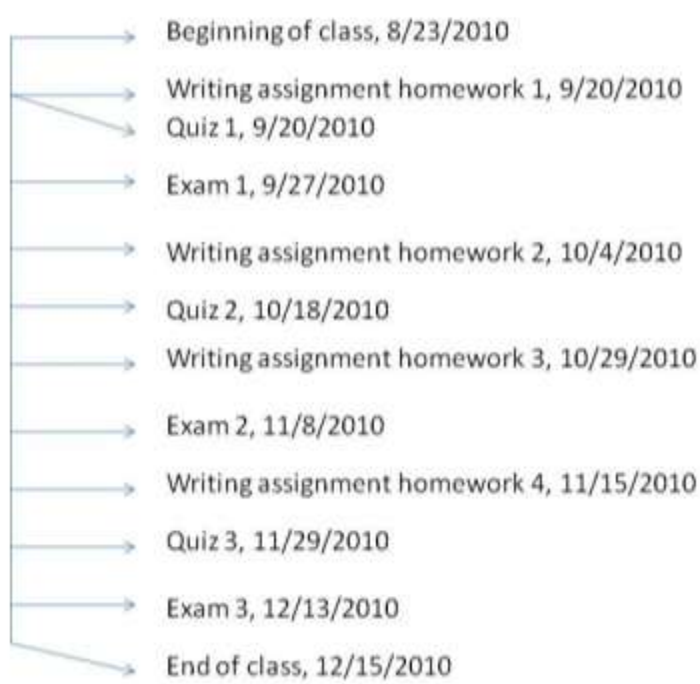


Finally, all writing assignments were collected from the student participants. However, scores on each writing assignment were not used in the study due to an overlap of rhetorical demands in the writing assignment instructions and characteristics of multimodal representation found in the researcher generated focused holistic rubric.

Qualitative data was collected by the researcher during the course of the semester. Classroom observations included audio recordings of most lecture and discussion sections with field notes illustrating relevant multimodal experiences. Personal semi-structured interviews were conducted with the teaching assistants, professor, and three student participants (Appendix D). These interviews were recorded with an audio device at a local chosen by the participant. Informal interactions with students outside of official class time were not recorded in field notes.

A time-line of the class schedule including writing assignments, quizzes, and exams is given below (Figure 2). This figure shows that a regular pattern of writing assignments, quizzes, and exams did not follow throughout the semester. Instead, the schedule resulted in two writing assignments preceding quiz 3 and two writing assignments preceding exam 2. Because of the staggered nature of the writing assignment timing to data collection, the data analysis frequently relies upon semester totals of MMR scores, quiz scores, and exam scores. The summation of the data collected also helps to improve the power of data analysis (see below). Although not listed on this class time-line of assessments, the personal interviews with student participants and instructors all occurred after the end of the semester, December 15th, in order to ask questions reflecting on learning progress throughout the course. Field notes were taken by the researcher during lectures and discussion sections from the first day of class through the last.

Figure 2: Time-line of Class Assessments



Analysis of the Research Data

The variety of research data collected was intended to provide enough perspective on the inter-actions and occurrences in the study so that accurate and valid inferences and conclusions could be drawn. The data analysis was a critical juncture during that process. The type of data collected during this required careful analysis in order to avoid misinterpretations or overstatements of the results. The principle research questions were answering using correlational data with some descriptive and qualitative data as well. Each of these data sources were analyzed according to their nature and the manner of their collection. Descriptive data was analyzed to inform subsequent inferential analysis, and qualitative data analysis contributed to both descriptive and inferential interpretations. Taken together, the results of the study provided the basis for the significance and implications from the study as well as possible future research.

Quantitative data analysis.

The quantitative data from this study included instructor scored classroom assessments with no influence by the researcher. Quizzes were written by the teaching assistants and the professor of the course, but exams were written only by the professor of the course. The teaching assistants graded and tallied quizzes, but all exams were scored by a computer system, Scan-tron. All writing assignment scores from teaching assistant grades were not used in this study. Instead, writing assignments were graded by the researcher using the focused holistic grading rubric for multimodal representation (MMR) knowledge and usage.

In order to summarize the general trends in student performance in this research study, a variety of descriptive statistics were used. The descriptive data analysis used in this study included means, standard deviations, linear regressions, and ranges calculated with a computer spreadsheet program. Kuder-Richardson Formula 20 (KR20) reliability scores were calculated for the exams by the university grading facility while the KR20 reliability for the quizzes was calculated using the computer program SPSS. Effect sizes were also calculated using the SPSS program.

The purpose of descriptive statistics is not only to "describe" the data from a measure (or study) but also to help find patterns within the data described. These patterns were used to inform inferential statistics as well (see below). Measures of central tendency and standard deviations indicated the overall performance of students in the class as a whole and in subgroups – different sections and different academic performance levels. Ranges and outliers will help describe the absolute limits of student performance in addition to what might be considered as likely or typical. Likewise, correlations were performed to show the trend of academic performance over the range of students. Standardized effect sizes measured by Cohen's *d* complements the following inferential data by providing information about the differences between groups that correlational data could not provide. These descriptive statistics were also used in subsequent inferential statistics but served the very valuable purpose of providing summative information about the overall distribution of academic scores and focused holistic rubric scores.

Inferential statistics used to identify correlational relationships and significant differences within the quantitative data for the purposes of answering the research questions were also performed using a spreadsheet computer program. Inferential statistics included Pearson product-moment correlations as well as Students' t-tests. For each inferential statistic, a probability value was given in addition to whether or not the test was statistically significant. Student t-tests were performed at the 0.10 level of significance with 2 tails due to its standard practice. Statistical significance for the correlational data was performed at the 0.10 level due to type I error (rejecting a true null hypothesis) being less of a threat to the interpretation of results than a type II error (accepting a false null hypothesis).

The inferential statistics used in this study are responsible for answering the quantitative aspect of the research questions. The inferential statistics accomplish this through null hypothesis testing, depending upon the type of data used and the research question under investigation. For determining relationships between student academic performances (exams and quizzes) and multi-modal representation ability, a number of Pearson product-moment correlations were used. These correlations illustrate the degree of relatedness these scores possess. That is, whether student academic scores tend to increase with focused holistic representational scores or vice versa – whether representational scores increase with academic performance. In a correlational study using correlation tests, there will not be any claim of causation from these tests alone. Instead, these correlations show a relationship that might exist between or among the variables in the study. Further tests or research would have to be performed in order to elucidate the direction of interaction or additional variables within that (those) relationships.

Qualitative data analysis.

General qualitative data analysis was used to analyze the classroom observations, student interviews and all written documents. An in-depth qualitative analysis such as the constant comparison method for grounded theory production was too advanced for this study. Instead, the quantitative data analysis formed the basis for answering the research questions. When the power of the quantitative data had been exhausted to answer the research questions, the qualitative data was analyzed to assist in the interpretation of results. Conversely, some qualitative data provided avenues to analyze the quantitative data in alternative manners to better investigate the research questions.

. **Research variables in the study.**

The primary variables in this research study which were of interest were the outcomes of student learning found in their summative assessments (quizzes and exams) and the representational knowledge use derived from the focused holistic rubric. Quizzes and exams cover a variety of genetics concepts segmented into major content units. For example, the first quiz covered material from introductory terminology to Mendelian and Non-mendelian genetics. Exams covered more content units than quizzes but all content units (ex. Population genetics) were covered in their subsequent exams.

In this correlational study, there is no variable which forms the basis for comparison between an experimental and control group of students. The factor in this study which is the focus of the paper is the introduction of a multimodal representation component to the student writing assignments. The primary data which forms the focus of this study is the multimodal representational scores determined by the focused holistic rubric. These scores are almost always included in the descriptive and inferential statistical analysis opposite the academic performance (quizzes and exams). However, since there is no section that did not receive the "intervention" of multimodal writing or not, there can be no claim of causality between the students' writing assignments and academic performance.

Normalizing exam data

The final exam for the Human Genetics in the 21st Century class was different from the first two mid-term exams not only in the content covered but also in the structure of the exam. The first two academic exams in the class were measured on a 102 point score scale. However, the final exam in the class was based upon a 225 point score scale. This difference in score scale presented a problem for descriptive and inferential statistics. In particular, comparisons of student performance across time and exams cannot easily be done since the data is on a different score scale. In order to observe patterns in performance and determine if there is a relationship between variables across time, a standard score scale is needed. As a result, the exam scores had to be normalized on the same score scale to allow for these comparisons and subsequent data analysis.

The final grade for the class included all points the students received on all of their work (exams, quizzes, and homework assignments). All together the final point total for the class was 520 points (204 for exams 1 and 2, 225 for exam 3, 51 for the quizzes, and 40 for the written assignments). From this range of scores, the instructor for Human Genetics in the 21st Century assigned overall grades (A, B, C, D, and F grades) based upon the College of Liberal Arts and Sciences guidelines for instructors. The cutoff scores for each grade level on this 520 scale were used to transform exam scores to a standard GPA scale. The cutoff scores for each grade level were assigned to the individual exam grade score scales in order to preserve the grade distributions. The scores on each exam were then converted to GPA scores that corresponded with those on the final class total and final grade scores. The GPA scores derived from each exam hold the overall College of Liberal Arts and Sciences recommendation for curving class grades (average GPA of 2.5). The normalizing of exam scores to GPA are also consistent with the overall class point total since each exam grade was a component of the overall point total and contributed to the final letter grade for the class. Using GPA scores for each exam, the students' academic performance can be compared across exams for descriptive and inferential statistics – particularly student t-tests and correlations. Raw exam scores were also used between sections for exam 1 and 2 comparisons. The raw scores are preferred during data analysis due to the preservation of the natural variation in student scores and greater sensitivity during inferential testing. By converting to GPA, the variance between individual student scores was lost to a certain extent, but comparisons across exams were made possible. However, raw score grades were only used with individual exams and could not be used to compare student performance over the course of the semester. The ability to compare GPA scores is especially important given the differences in content difficulty between different exams. Student quiz scores did not have to be normalized across iterations since all quizzes were based upon a 17 point scale so all raw scores are used. Likewise, all student writing assignments were of comparable length so there was no need to weight student performance in writing composition using the focused holistic rubric based upon the length of the paper so all MMR scores are unmodified as well.

Table 2: Summary of the Research Design

Research Questions	What is the relationship that is found between multimodal representations in student writing assignments to their academic performance in classroom assessments? How do the factors which contribute to multimodal representation competency relate to improved classroom performance? Are there any factors outside of the students' classroom writing or assessments which significantly influence, directly or indirectly, their performance?
Research variables	Academic performance on quizzes and exams: raw, GPA Multi-modal representations: focused holistic rubric, number of modes, type of modes, originality
Data Collected	Quantitative: Writing assignments; Quizzes; Exams; Qualitative: Classroom observations: lecture, discussion; Personal interviews: students, teachers; Writing assignments
Data Analysis	Quantitative: Descriptive statistics: all quantitative data; Correlations: representational, academic performance; Student's t-test: representational, academic performance; Chi-square test: representational data Qualitative: General: observations, interviews, written assignments

CHAPTER IV: RELATIONSHIPS WITH MODAL REPRESENTATIONS

This chapter provides all of the essential results from the study that will provide the reader with an understanding of the academic and multimodal performance of the students in the Human Genetics in the 21st Century class at the University of Iowa during the Fall 2010 year. This study has a large variety of research data that contributed to the increased knowledge of the relationship between students in a college biology classroom and their development of science literacy. The guiding research question for this study was to determine what the relationship or relationships are between multimodal representation by genetics students and their science literacy. In order to answer the study question, a number of data types were collected in order to provide evidence for that question's answers. The primary source for data about the status of their science literacy was their academic performance in the class on their quizzes and exams and MMR scores. In order to operationalize the students' multimodal representational usage, a focused holistic rubric was used to score their four writing assignments. Additional qualitative observations and interviews were collected as well in order to help explain the relationship the nature of the quantitative results. All of the data from this study are intended to complement one another in order to provide evidence for the interpretation of what relationships exist between multimodal representation and science education.

Student Performance in the Study

The Human Genetics in the 21st Century class have a number of interesting distributions of scores over the course of the study. The primary descriptive statistics from this study come from the exam, quiz, and writing assignment scores. In addition to the course-related academic scores, the focused holistic rubric scores derived from the writing assignments provide the other major source of data from this study. The multimodal representation (MMR) scores were used to describe science literacy performance on writing assignments instead of the course grades given by teaching assistants due to the focus of the study, multimodal representation.

The MMR scores were significantly different for the first student writing assignments whereas no other set of writing assignments yielded significantly different scores between sections (Table 2). This result indicates that there was a significantly higher use of multimodal representation knowledge by section 1 over section 2. This result could have many possible reasons for the difference. The first possibility of these differences is that both sections are in fact very similar in their multimodal representation knowledge, but this similarity is not observed because the focused holistic rubric only measured observed multimodal representation use. The students of section 2 may possess the same level of knowledge but do not utilize this knowledge to the same degree as section 1 students. Another possibility for the difference is that the students in section 1 possessed higher multimodal representation knowledge or experience than the students in section 2. Since no pre-test was given to the students, this possibility cannot be determined with the data available. Another possibility is that the type of rhetorical task given to the students which differed by section led to higher multimodal representation scores. Section 1 was given an inquiry-based rhetorical task while section 2 was given a reflective-based rhetorical task. The sections were counterbalanced by rhetorical task in order to prevent any effect upon subsequent quiz or exam performance. Since there was not a significant difference between scores on the second set of writing assignments or any other, then it is unlikely that the rhetorical tasks in themselves contributed to this result – at least, not in isolation from other factors. The effect size for the first writing assignment was very large according to Cohen's guidelines for interpretation and supports the statistical difference between the two groups. The other effect sizes between the groups were between small and medium and indicate that the differences between the groups varied over time but did not show a consistent trend in one direction or another.

Table 3: Student Multimodal Representation Scores by Section

	MMR 1 Mean (SD)	MMR2 Mean (SD)	MMR3 Mean (SD)	MMR4 Mean (SD)
Section 1	2.11 (1.29)	2.21 (1.10)	2.65 (0.90)	2.53 (0.92)
Section 2	0.63 (0.97)	2.67 (1.17)	2.33 (1.37)	2.08 (1.17)
Cohen's *d*	1.29	-0.405	0.276	0.428
Independent Means T-test	3.77	1.19	0.829	1.27
p-value	< 0.001*	0.157	0.578	0.325

Note: $^*p < 0.10$

From classroom observations, an alternative interpretation is more appropriate to explain this result. The instructions given to the two sections differed slightly due the instructions of the rhetorical task and by teaching assistant. The teaching assistant for section 1, Ben, was clearer in his description of the expectations for completing the writing assignment than the teaching assistant for section 2, Amy. Both sections did receive slightly different instructions for their writing assignments since there was counterbalancing of the different writing assignment rhetorical tasks. However, the set of instructions pertaining to the inclusion of the extra mode of representation was the same for both sections' instructions:

> Given the complexity of this topic, a representation of the concept you are discussing can help your explanation. Use a figure, table, graph, math equation, etc. to help you summarize what you have learned so far. Provide a brief explanation for why this representation helps summarize what you have learned about the genetics topic (Appendix A).

The second sentence of the instructions uses the imperative "Use" in order to indicate that the students were required to have at least one multimodal instance in their paper. However, the second section interpreted the teaching assistant's verbal instructions during class about the writing assignment expectations differently from the first teaching assistant's instructions. The students from the second section reported that they interpreted Amy's verbal description of the writing assignment instructions to be that a multimodal instance could be included but did not have to be included (see qualitative data below). This difference in instructions by the teaching assistants drastically altered the perception of the writing task by the students. As a result, the second section had significantly fewer multiple modes used in their writing assignment compared to the first section, 2 to 24 respectively. Since students who do not include multiple modes will not receive higher MMR scores, this difference in interpretation by the students of the writing assignment instructions led to a statistical difference in their MMR scores.

After the first set of writing assignments, the students were given additional instruction by the teaching assistants about how each of them graded their assignments. During this conversation, Amy, the teaching assistant for the second section, provided clarified instructions for her section about what the requirements were (field notes, September 26, 2010). In this case, it was to emphasize that the inclusion of a multiple mode of representation was required. Once the instructions were clear to the students, the number of multiple modes used by the second section approached equality with the first section - 16 to 18, respectively. This closer number of modes between sections continued through writing assignments 3 and 4. There were no significant differences in the MMR scores between sections 1 and 2 for writing assignments 2 through 4 as well (Table 1). The writing assignments were completed on the weeks of September 20^{th} (MMR 1), October 4^{th} (MMR 2), October 29^{th}(MMR 3), and November 15^{th}(MMR 4), 2010.

Since the students differed significantly in the first writing assignment, important differences may also exist for the academic performance. The students' academic performance was measured by both quizzes and exams. Their overall academic performance in the entire course included their scores on their writing assignments issued by their teaching assistants. However, these scores were not used as part of the assessment of their academic performance due to the overlap of writing tasks and grading. The grading rubric issued by the teaching assistants included aspects (multiple mode included or not) that were similar to the MMR grading rubric. As a result, these two sets of assessments would be measuring very similar educational tasks and outcomes. Therefore, the teaching assistant assigned scores for the writing assignments were not used as a comparison with MMR scores. Likewise, the overall course score and grade was not used since these also included the teaching assistant homework grades.

Students were given quizzes (1 through 3) on the weeks of September 20^{th}, October 18^{th}, and November 29^{th}, 2010. Quizzes were completed during class time in discussion sections and were allotted 30 minutes for completion out of 50 minutes of class time. Quiz questions were varied and included short answer essay, matching, labeling, True/False, and drawing of figures. Although each quiz had a total of 17 points, the number of questions varied - depending upon the weighting of difficulty per question – from quiz to quiz. From the quiz scores, there were no significant differences between sections using independent means students' t-tests (Table 3). This finding implies that the instructions and quizzes given to each section were not significantly different. The effect size differences between the groups show that for quiz 2, a moderate reversal was seen between sections 1 and 2 in favor of section 2. However, this reversal was reversed again by a medium effect size once again. The alternating differences between the sections indicate that the factors which lead to quiz performance are very dynamic in nature. This finding is important because, unlike the exams, each section was given alternate forms of the quiz, similar to the writing assignments. Both forms of the quiz, for section 1 and section 2, were written in cooperation between both teaching assistants and the professor. When the quizzes were graded, both teaching assistants collaborated on those scores as well. Both quiz forms had the same number of questions and covered the same content but some questions may have differed by the numbers or terms within each question. Since there is no difference between sections on the quizzes, the difference between the quiz forms given to each section would not appear to be a problem for the interpretation of other results.

The exam averages can be seen below in their raw score form and their adjusted Grade Point Averages (GPA) due to differences in score scale between exams 1 and 2 and 3 (Table 4). Exams 1 and 2 were given during class time and were shorter in length of material and time allotted for the students to complete the examination and had a 102 point score scale. By contrast, the final exam was conducted outside of normal class

Table 4: Student Academic Performance on Quizzes by Section

	Quiz 1 Mean (SD)	Quiz 2 Mean (SD)	Quiz 3 Mean (SD)
Section 1	11.4 (3.51)	9.26 (3.16)	13.1 (2.53)
Section 2	9.36 (4.00)	10.7 (4.11)	10.9 (4.16)
Cohen's *d*	0.542	-0.393	0.639
Independent means	1.89	1.15	1.92
T-test p-value	0.220	0.126	0.146

time and was approximately twice as long in time allotment as well and had a 225 point score scale. The final exam was not cumulative even though a significant proportion of the material from earlier in the course is required to understand subsequent content.

Table 5: Student Academic Performance on Exams by Section

	Exam 1 GPA Mean (SD)	Exam 2 GPA Mean (SD)	Exam 3 GPA Mean (SD)	Exam 1 Raw Mean (SD)	Exam 2 Raw Mean (SD)	Exam 3 Raw Mean (SD)
Section 1	2.76 (0.65)	2.61 (0.79)	2.70 (0.79)	81.6 (9.92)	65.7 (13.3)	162 (21.9)
Section 2	2.14 (0.95)	2.24 (1.03)	2.13 (0.98)	71.8 (17.7)	59.4 (17.7)	145 (25.7)
Cohen's *d*	0.762	0.403	0.640	0.683	0.402	0.712
Independent means	2.28	1.20	1.91	2.06	1.20	2.11
T-test p-value	0.0667*	0.373	0.114	0.0706	0.267	0.0559

Note: *p < 0.10

There was not a statistical difference between sections 1 and 2 based upon exam scores, and there is a consistent trend among the scores in favor of section 1 (Table 4).

The effect sizes between the sections was the most dramatic for exam one, supporting the statistical significance. However, like quiz 2, the second exam showed a reduction in effect size in favor of section 2. For exam 3 raw scores, the difference in scores approaches the level of significance (0.05) but does not quite cross the level for the raw scores. Exam 1 scores between the sections also approaches the level of significance – though less so – for the adjusted GPA scores. Due to the score scale differences between exam 3 and the other exams, it is difficult to make assessments of student performance across exams using only the raw scores. When the GPA scores are compared across exams, the overall progression of scores follows a similar pattern to the quiz scores.

The pattern of scores across all of the measure above shows an interesting pattern between the first couple of multimodal representation scores and academic scores. There was a statistical difference between scores of section 1 and 2 for the first writing assignment. When comparing scores on quizzes and exams, the performance of the second section is lower than that of section 1 on quiz 1 and exam 1 but not quiz 2. In fact, section 2 has a higher average than section 1 on quiz 2. Although that comparison was not statistically significant, there was a statistically significant increase in the section's MMR scores from writing assignment 1 to writing assignment 2 using dependent means Students' t-test statistics (Table 5). This dramatic increase in the section's MMR scores may indicate that their experience with multiple modes of representation had an effect on that section's science literacy during the course of the semester. If that happened, then it may help explain why section 2 had a higher average than section 1 on quiz 2. Although section 2 students did not exceed the scores of section 1 on exam 2, they did close the gap. The difference between GPA means of section 1 and

2 on exam 1 was 0.62 while on exam 2 it was 0.37 (Table 4). The interpretations of these results are very tentative, but they do reveal an interesting pattern that deserves further investigation into their origin.

Unfortunately, the improvement by section 2 did not carry over to exam 3 for the students as they slipped back to 0.57 GPA difference with section 1. The same pattern was seen between quiz 2 and quiz 3 when section 1 students once again yielded a higher average than section 2 (Table 3).

Table 6: Multimodal Representation Scores by Section with Dependent Means

	Section 1 Mean (SD)	Section 2 Mean (SD)
MMR 1	2.11 (1.29)	0.63 (0.97)
MMR 2	2.21 (1.10)	2.67 (1.17)
Cohen's *d*	-0.0834	-0.968
Dependent means T-test	0.257	5.37
p-value	0.725	<0.001*
MMR 2	2.21 (1.10)	2.67 (1.17)
MMR 3	2.65 (0.90)	2.33 (1.37)
Cohen's *d*	-0.438	0.267
Dependent means T-test	1.34	0.755
p-value	0.300	0.384
MMR 3	2.65 (0.90)	2.33 (1.37)
MMR 4	2.53 (0.92)	2.08 (1.17)
Cohen's *d*	0.132	0.196
Dependent means T-test	0.406	0.551
p-value	0.774	0.535

*p < 0.10

Unfortunately, since this study did not use a strong experimental design, the exact influence the students from section 2 gained from that significant increase in multimodal representation knowledge and experience is difficult to determine from these data. However, if section 2 students did receive a pivotal increase in multimodal representation knowledge and it influenced their overall science literacy, then it is consistent with numerous other studies which testify to its importance in student learning (Gerler, 1979; Hassett & Curwood, 2010).

In order to further investigate the research question of what relationship exists between multimodal representation and the students' science literacy, a number of correlations were performed using the multimodal representation rubric scores and their academic performance scores from quizzes and exams. Correlations were needed to investigate the research questions because Pearson product-moment correlations can display a linear relationship between two variables. The principle variables which are of interest in this study are students' multimodal representation knowledge – as measured by rubric scores – and their science literacy – as measured by academic performance scores. Admittedly, neither of these two measures can completely capture either of the domains which are quit broad and complex. The purpose of the following correlations is to provide enough information into the extent of their relationship to inform classroom practice and further study. From the descriptive data above, it appears that there may be an observable effect between the multimodal representations of students and their academic performance in the class which will be of importance.

Multimodal Representation Correlations and Results

Research question 1: What is the relationship that is found between multimodal representations in student writing assignments to their academic performance in classroom assessments?

The relationship between multimodal representation and academic performance to investigate science literacy can be answered using correlational data between those factors. The correlations with the students' multimodal representation scores as derived from the focused holistic rubric to their academic scores on quizzes and exams produce inconsistent patterns of significance. From the research literature, the importance of multimodal representation to learning in the science classroom would imply that multimodality is an integral and important driver of science literacy (Carolan, Prain, & Waldrip, 2008; Lemke, 2000). Perhaps the broadest and most reliable correlations are those of overall student progress throughout the course. These scores are composite scores using all of the quiz and exam data collected throughout the semester. Since these scores are drawing upon a larger pool of data, they will have a more reliable measure with greater power than individual quiz and exam data. The correlation of all students, sections 1 and 2, of their MMR scores over all of the quizzes and exams provides the highest level of power from the most data drawn from (Table 6). However, there was no significant positive (or negative) correlation between total class MMR scores and academic performance on total exam scores, revealing that there is no significant tendency for students to have higher exam scores with higher multimodal representation usage on their writing assignments, $r(34) = 0.203$, $p > 0.10$. However, there was a significant correlation between MMR scores and total student quiz scores, revealing a tendency for multimodal representational knowledge to be associated with better quiz performance, $r(32) = 0.304$, $p < 0.10$.

Both correlations were positive but not strong as the body of literature has indicated the relationship between multimodal representation and science literacy to be (see Chapter 2). The correlation with quiz scores was only slightly beyond the level of significance, t = 1.694, at the 0.10 level.

Table 7: Correlations Between Multimodal Representation Scores and Academic Scores

	Total Class MMR scores Pearson r-value	Total Class MMR scores T-test statistic	Total Class MMR scores p-values	Total Class MMR scores Cohen's *d*
Total Exam scores	0.203	1.18	0.246	0.414
Total Quiz scores	0.304	1.81*	0.079	0.638

Note: *p < 0.10

These two results indicate that the relationship between multimodal representation and student academic performance over the course of this genetics class is complex since single correlations are not adequate to explain a majority of the variance. Other factors must be connected to science literacy in this context to be contributing to the overall effects seen. Although one of these correlations revealed a significant relationship, additional correlations and analysis are needed to further capture the many different facets that existed within the Human Genetics in the 21st Century class and the students' multimodal representational knowledge.

Research Question 2: How do the factors which contribute to multimodal representation competency relate to improved classroom performance?

There are a wide variety of factors that can be analyzed within the class that may relate to students' multimodal representation knowledge or usage. There were individual components within the MMR rubric which informed the overall holistic score which may be important, such as the number of modes used by students or the number of original modes created by the students. Even though a specific type of mode used by the students was not hypothesized to be of significance, the type of mode used by students may have influenced their MMR or academic performance as well (Hand, Gunel, Ulu, 2009). Finally, since there was a statistical difference between the two sections at the beginning of the course in the levels of MMR scores on the first writing assignment and exam, a difference may exist in the relationships seen in their correlations as well.

The development of science literacy through multimodal representation knowledge requires experience with multiple modes of representation in science to build competency (Waldrip & Prain, 2006). Students in the Human Genetics in the 21st Century class would likewise need to have experiences in class reading, interpreting, and even creating multiple modes of representation in order to build their competence with them during the class. In order to do this, the number of modes used by the students may be just as important as the quality of the representation – as measured by the focused holistic rubric. As with the total MMR scores seen above, there was no statistical significant correlation between the total number of modes used by students in their writing assignments and their total exam scores, $r = 0.249$ (32), $p > 0.10$ (Table 7). However, as with total MMR scores, there was a statistically significant correlation between total multiple modes used by students in writing assignments and their total quiz scores implying that there is a positive relationship between the two variables, $r = 0.304$ (32), $p < 0.10$. Once again, though, both of these correlations are rather weak in contrast to their predicted strength upon science literacy.

Table 8: Correlations Between Academic Performance with Total Multiple Modes Used

	Total Multiple Modes Pearson r-value	Total Multiple Modes T-test statistic	Total Multiple Modes p-value	Total Multiple Modes Cohen's *d*
Total Exam Scores	0.249	1.45	0.156	0.514
Total Quiz Scores	0.304	1.81*	0.079	0.638

Note: *p < 0.10

The total number of multiple modes used by students does not necessarily reflect the type of learning that may be occurring with their usage. Many students included modes of representation in their writing assignments which were not original productions but were taken from the source material or another source related to their writing assignment topic. The cognitive processes that must occur during reading, decoding, and interpreting of modes seen by the students can be quite different from those needed to write, conceptualize, and create modes (Galbraith, 1992; Waldrip & Prain, 2006). In order to determine if there is a relationship between the creation of novel modes by the students their academic performance, an additional set of correlations was performed (Table 8). However, there was no statistical significance between the total number of original modes created by the students and either their total exam or quiz scores, r = 0.257 (32), p > 0.10; r = 0.134 (32), p > 0.10. Although this relationship may be very important to the students' science literacy development, it is very difficult to interpret this particular set of correlations due to the extremely low number of original modes produced by the students. The low number of instances of modal use will affect the power to detect a true effect in this study (see Discussion).

Table 9: Correlations of Academic Performance with Total Original Multiple Modes

	Total Original Modes Pearson r-value	Total Original Modes T-test statistic	Total Original Modes p-value	Total Original Modes Cohen's *d*
Total Exam Scores	0.257	1.50	0.143	0.532
Total Quiz Scores	0.134	0.764	0.450	0.270

Note: $*p < 0.10$

The multimodal representation experiences by the students may also vary according to the specific type of mode used by each student. There are certain biological concepts which are canonically represented in certain ways in the genetics community. For example, the mode of inheritance is most often depicted in a diagram of genealogies, a pedigree. For students to determine the mode of inheritance from a set of data, it is most likely that they will be given a pedigree of afflicted patients from which to perform that induction. Students who are familiar with interpreting this mode will have a greater degree of modal competency with pedigree problem solving than a peer who is naïve to their interpretations. The type of modes chosen by students include in their writing assignments may, therefore, have an impact on the rate or direction of their science literacy development in the class.

In order to determine whether or not a relationship existed between the type of mode used by students in their writing assignments and subsequent academic performance, the modal preference of each student was determined from their overall modal usage in writing assignments. In the Human Genetics in the 21st Century class, the multiple mode categories which appeared in student writings were tables, pictures, diagrams, graphs, math equations, and even poems. The number of each type of mode used by each student was recorded and a median of each type of mode used was determined by the percent of times that mode was used in all of the students' writing assignments. If a student had a modal usage above the median percentage for that type of mode, then they were considered to have shown a preference for that mode. The students were then grouped according to their modal preference: students preferring tables, students preferring graphs, etc. Occasionally some students used different types of modes equally. These students were grouped together as showing no preference to any mode (Table 9). From the academic performance by modal preference (or other preference), a difference t-test was performed in order to determine any differences between the modal preferences. Interestingly, there was a statistically significant difference between the group of students who showed a preference for diagrams compared to those who did not on quiz scores, $t = 1.306$ (13), $p < 0.05$. This result indicates that students who showed a preference in their writing assignments for diagrams had a higher set of quiz scores compared to those students who showed other preferences.

Table 10: Student Academic Performance by Multimodal Preference

Modal Preference	N	Total Exam GPA Mean (SD)	Students t-test p-value	Total Quiz Scores Mean (SD)	Students t-test p-value
Picture Preference	10	7.47 (2.32)	0.992	31.8 (11.9)	0.988
Diagram Preference	13	7.95 (1.88)	0.355	36.5 (6.64)	0.021*
Table Preference	2	8.01 (1.66)	0.789	31.5 (8.00)	0.975
No Preference	11	6.77 (2.81)	0.321	26.3 (6.88)	0.227

Note: $*p < 0.10$

Research Question 3: Are there any factors outside of the students' classroom writing or assessments which significantly influence, directly or indirectly, their performance?

As with most educational studies, the presence of additional variables that impact the main research question must always be investigated to better understand the context of the results. From the descriptive data analysis, there was a statistically significant difference between sections 1 and 2 based upon their first writing assignment and exam 1. In addition, there was a statistically significant improvement in overall MMR scores from writing assignment 1 to writing assignment 2 by section 2 students. These results may indicate that a difference in correlations between the two sections is not being reflected by combining the two groups for overall classroom performance. Of particular interest is whether or not section 2 showed a more positive correlation than section 1 on either quizzes or exams with their first or second writing assignment. If the increase in MMR scores from writing assignment 1 to writing assignment 2 had an influence of the science literacy development of section 2, then that section should show a stronger positive correlation in on their second quiz and second exam.

Table 11: Correlations between Student Sections and Academic Performance with Multimodal Representations Scores

	Section 1 MMR scores Pearson r-value	Section 1 MMR scores p-values	Section 2 MMR scores Pearson r-value	Section 2 MMR scores p-values
Exam 1 scores	0.193	0.289	0.139	0.448
Quiz 1 scores	-0.0852	0.643	0.00484	0.978
Exam 2 scores	0.0527	0.773	0.478*	0.00570
Quiz 2 scores	0.285	0.114	0.213	0.242

Note: $*p < 0.10$

There was a statistically significant positive correlation between section 2 students' MMR scores and their exam 2 scores, $r(16) = 0.478$, $p < 0.10$ (Table 10). This correlation was much more positive than their correlation on quiz 1 ($r = 0.139$ to 0.478). Likewise, section 2 also increased in correlation from exam 1 to exam 2. However, section 1 also saw increases in their correlations as well. Interpretations of this set of data is particularly problematic due to the lower sample size each section will have individually rather than the combination of the two sections contributing toward a correlation.

A number of correlations were practically zero – practically no association between variables at all. The lower sample size for each group (section 1 = 19 students, section 2 = 16 students), allows for outliers to skew the data in a direction that it would not be found in the larger population size correlations. The scatter plots illustrating these correlations reveal that the smaller sample size may have been a factor in the values and directions of these correlations (Figures 3 & 4). The lower reliability and power that is a consequence of the small sample sizes is the reason that the best measures for determining an overall relationship between science literacy and multimodal representation were found with the composite quiz and exam data (Tables 7 and 8).

As a result of these smaller sample sizes, a reduction in the power to detect a real educational effect has also been reduced. Although the statistically significant exam 2 correlation by section 2 students is consistent with the previous data, the limitations of the data present problems during interpretation. The inclusion of classroom observations and interviews in this study was intended to supplement the quantitative data in the event that the lack of power caused problems for interpretations. A number of problems have

Figure 3: Marginal Relationship between Section 1 Quiz and Multimodal Representation Scores

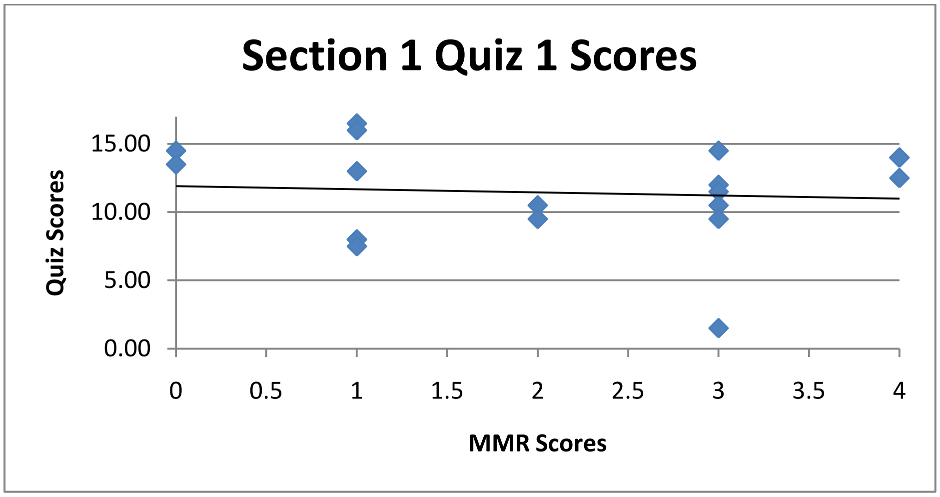
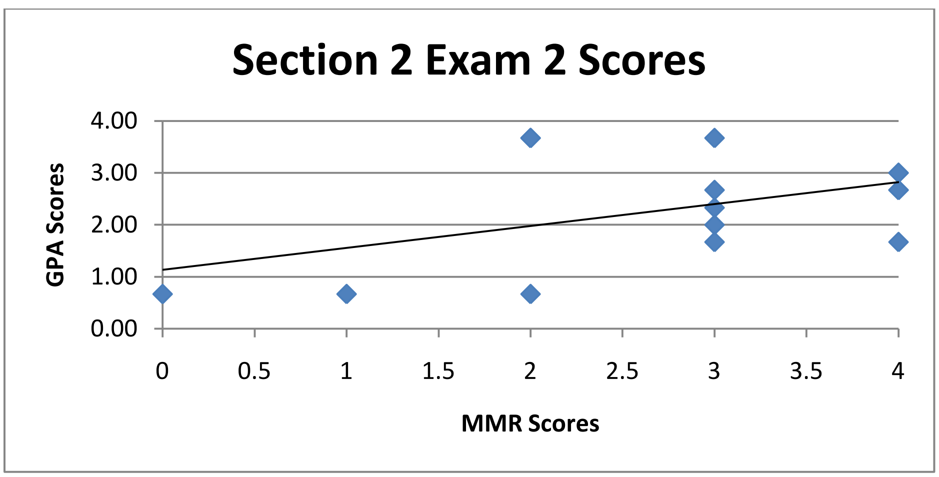


Figure 4: Tenuous Relationship between Section 1 Exam and Multimodal Representation Scores



arisen in the course of the data analysis which the classroom observations and interviews will help in the interpretation of the data. In particular, qualitative data from classroom observations will aid in the determination for why section 1 and section 2 had significant differences between them. Also, the qualitative data from student interviews may provide useful information for the interpretation for why quiz and exam scores do not correlate stronger with multimodal representation scores.

Classroom Context of Student Performance and Results

The first, and most important, classroom observation which has aided in the interpretation of the quantitative results have been the reason behind the statistical difference between sections 1 and 2 on the performance of their first writing assignment's multimodal representation scores on the focused holistic rubric (see above). However, another problem in interpretation of the results has been the consistently low levels of correlations between multimodal representation scores and the students overall academic performance which were not expected. Document analysis, classroom observations, and student interviews are able to shed light into why most of the correlations were not as strongly significant as expected. Finally, the classroom observations and interviews allow for a reasonable interpretation of what relationship exists between multimodal representation by the students and their academic performance in the class.

As discussed above, the directions and interpretations of the directions between the sections for the first writing assignment were different. One student, "Julie", in section 2 complained after missing a point on her paper because she did not include a multiple mode of representation, "…but my paper didn't have a figure in it. What am I supposed to do if it doesn't have one (Field Notes, 9/27/10)"? The student, and many others, read articles (which were required as an attachment to their assignments) from newspapers that did not have a scientific figure in it. They did not understand that they were still responsible for including a figure in their paper even though the article they read did not. After this classroom discussion had finished, the teaching assistant for the second section, Amy, was able to adequately clarify the expectations for the writing assignments and grading rubric. For the second writing assignment, students from both sections may have purposely chosen articles which had figures in them while there were some writing assignments turned in with more than one article. Two articles were not required for the paper, but the students read one article for the majority of the content and the other article was used because it contained a figure that they used to satisfy the grading requirement. As a result, the number and MMR scores for section 2 were statistically higher for the second writing assignment and gradually receded over the next two assignments.

Another problem in the data analysis that arose during this study was the lack of consistent statistically significant correlations between MMR scores and academic performance. If students were developing their science literacy during the course of the semester, then their competency should improve over the course of the semester as well. However, the overall MMR scores for both sections did not change much after the second writing assignment (Table 2). The content of each writing assignment changed to reflect the progression of content in the course. The first writing assignment covered Mendelian genetics, the second writing assignment covered non-Mendelian genetics, the third assignment covered chromosomal anomalies and cancer, and the fourth writing assignment covered DNA mutations and evolution. The progression in content reflected a progression in difficultly for the conceptions the students were required to learn. The number of writing assignments which included scientific journals as source material increased slightly over the course of the semester from 5 on the first writing assignment to 6, 7, and 9 primary sources, respectively. The number of secondary sources also increased to the point that writing assignment 4 had 9 primary articles, 22 secondary articles, and only 4 popular newspaper articles. As the complexity of the content increased, students were forced to find information from increasingly complex science resources. As the content increased in difficulty, the students have a greater challenge to their science literacy skills to compensate. In the context of this study, this increase in difficulty of science content and representations in source material helps to explain why a consistent increase in MMR scores would not have been observed across time, particularly in the latter half of the semester.

The relatively flat performance of students' MMR scores after the second writing assignment may also be due to complacency of the students. The students were not grading according to their level of multimodal representation knowledge by their teaching assistants. Instead, they were graded only on whether or not they included a multiple mode (0.5 points/10 total) and whether or not it was satisfactorily described in the paper (0.5 points/10 total). As a result, students who received full credit for their single modal use may not have seen any benefit from performing additional multimodal work. One of the students, "Vincent", described his writing process as, "When writing a paper, I'll typically outline my plan, but in this class the outline is more or less provided already (Interview, 12/7/2010)." This student was referring to the writing assignment instructions handed out during class. Indeed, the teaching assistants' grading rubric almost followed the handout instructions as bulleted points (Appendix A). As a result, it is not surprising that college students would not have a significant increase in MMR scores over time since they may not have been trying to improve their multimodal representational skill after the second writing assignment.

Finally, the relationship between the student's MMR scores on their writing assignments may not be as strongly associated to their academic performance as a result of the nature of the writing assignments' task. The task for each writing assignment changed slightly from one to another. However, each of them asked the student to consider only one major topic of genetics (Mendelian, non-Mendelian, cancer, and evolution). Although each of those topics are quite broad and have an extensive set of literature available for the students, the specific articles that they chose to read for the assignment may not have encompassed a great enough breath of the concept to be of a significant aid to the students' subsequent learning and work in the class. A contrast of the experiences between the students "Vincent" and "Catherine" help illustrate this randomness of effects to their multimodal representations. When asked about how the writing assignments may have helped him in the class, the student "Vincent" said, "I guess the main thing I got out of it was that what we covered in class was only the tip of the iceberg, and there are many other things going on… (Interview, 12/7/2010)" By contrast, the student "Catherine" said, "The knowledge I gained from one of the writing assignments helped me with a certain topic that appeared on a quiz and the final exam, and it was easy for me to recall the information since I had done so much research with the topic, (Interview, 12/6/2010)" For one student, the writing assignment experiences did not directly benefit his performance on quizzes or exams while the other student did. Since each writing assignment covers only one subject and quizzes and exams cover many subjects, it is reasonable to conclude that each writing assignment would not be contributing to each student's academic performance with the same strength. That is, a MMR experience in their writing assignment may only benefit a student indirectly on a subsequent quiz or exam.

Additional in-depth research into the weekly discussion meetings would have to be performed to determine whether the numerous multimodal representations which were experienced each week had a more direct influence on the student's subsequent academic performance than the 4 formal multimodal experiences. Likewise, the students were also exposed to numerous modes of representation in lecture and during the reading that they did for their homework assignments which were not recorded. All of those experiences combined with the multiple modes used by the students in their writing assignments composed the total multimodal representational experience of the Human Genetics in the 21st Century class. Unfortunately, the vast majority of the informal multimodal experiences by the student are not captured with the formal writing assignments and assessments (quizzes and exams). The students' writing assignments and academic performance are only snapshots in time of their overall learning process with multimodal representation. It is the combination of all of the experiences in the classroom that are contributing to student's science literacy. The correlations which attempt to investigate those relationships cannot encompass those other important experiences by the students which contribute to their science literacy. One of the best summarizations of the situation was from the student Catherine who said, "The discussion section was the most helpful [part of the class] in terms of learning biology. It is easier for me to remember a topic if I can discuss it and use demonstrations to visualize the concept (Interview, 12/6/2010)." From Catherine's beliefs, it is likely that more multimodal learning is occurring in the discussion sections than in the process of composing the writing assignments, completing quizzes or exams, and maybe even as much as attending lecture.

The lectures themselves were intended by Dr. Matthews to address specific misconceptions that he did not want his students to develop. An example of such a misconception would be that the phenotypic state is the same type found at the molecular level of a plant or animal. During non-Medelian genetics (covered by the second writing assignment, quiz, and exam), the differences between incomplete and co-dominance were discussed and explained by the professor to be found at all levels of biology – not just the phenotypic level. The professor specifically showed the distinction that the proteins which produce the phenotype may or may not be incomplete or co-dominant at all levels of the organism. The professor used the example of the AB blood type and petal pigmentation in snap dragons. The proteins which produce the blood types, A and B, are both produced on the red blood cells of an AB positive blood type person – molecular co-dominance and phenotypic co-dominance. However, both the white and red pigments which give rise to red and white snap dragons are also produced at the molecular level to create a pink petal snap dragon – molecular co-dominance with phenotypic incomplete dominance. There is no pink colored protein which creates a pink snap dragon (field notes, October 11, 2010). Dr. Matthews used numerous other examples throughout the semester to specifically address misconceptions that he intended to prevent being accepted by his students.

Dr. Matthews also attempted to engage students in lectures to contribute to a classroom dialogue which he could informally assess their learning progress. However, on some of the exams, the questions did not draw upon student experiences in the manner that his students had perceived the lecture content. For example, a question on exam 2 that proved particularly problematic for students who read, "What was the significance of the Avery-Macleod-McCarty (1944) experiment to genetics? (field notes, November 8, 2010)" For the exam question, foils A and B were quite similar in wording. Foil A was worded that bacteria could be transformed because DNA was being carried into the nucleus. Foil B was worded that bacteria could be transformed because genetic information was being carried into the nucleus. Unfortunately for students, many did not understand the point of the second foil. Technically, foil A is correct given what is known today. However, DNA was not determined to be the material of genetic information until the Hershey-Chase experiment of 1952. From most students' perspective, foil A is correct and foil B (although the correct answer) did not reflect years of biology learning which reinforces the already known conclusion that DNA is the material of genetic information. For most students, there was not need to continue reading other foils as option A was the most correct according to their conceptual understanding and prior experience. Unfortunately, the intention of the question was to assess whether or not students could draw the same inference from the single Avery-Macleod-McCarty experiment that scientists at the time came to. This ability included the recall of the fact that the Hershey-Chase experiment came afterwards and that DNA, as a biological term, had not yet been defined and could not be the most correct option for the question. Although this one question is not representative of all questions on the Human Genetics in the 21st Century class exams, it does illustrate the format and an example of the type of reasoning skills that were required of the students during their lecture exams.

The significance of investigating the relationship between the multimodal representations student produced during their writing assignments and subsequent performance in their class was supported by both students and teachers. The real-time learning of students using multimodal representations in classes will be an interesting avenue to further the future investigation of the role of multimodal representation in science literacy development.

CHAPTER V: CONTRIBUTIONS OF THE STUDY TO EDUCATION

The purpose of this chapter is to provide the reader with the interpretations of the results, the limitations of the research design, and the implications of the study. The discussion of results is important to this study given its complexity and difficulty to interpret. Part of the difficulty of the data analysis arises from the research design. Although limited in power, this correlational study had numerous factors which could contribute to an improved understanding of science literacy in a college level genetics classroom. Determining what relationships exist in this classroom between multimodal representations and science literacy will have important implications for science pedagogy and professional development.

Discussion of the Research Questions

Research question 1: What is the relationship that is found between multimodal representations in student writing assignments to their academic performance in classroom assessments?

The principle results which informed the answer to this question were derived by operationalizing multimodal representation usage by the students through the focused holistic rubric. Using the focused holistic rubric scores, correlations were able to be performed with quiz and exam scores. These correlations showed that a statistically significant positive correlation did exist between MMR scores and total quiz scores by students in the class. Because only quiz scores were statistically significant and not both quiz and exam scores, this study does not claim that the relationship between student multimodal representations is the main contributor to academic performance in general. However, previous research (see above) does not describe multimodal representation as the sole gateway to science literacy but a key component to the complex process by which it arises (Lemke, 2000). This study supports the argument that multimodal representation in the science classroom is part of a large, complex process by which students gradually increase their competency in the language of science. This study also support the growing body of literature that emphasizes the need for further research into its origins and development due to its significance and implications to the improvement of science education (Hand, Gunel, &Ulu, 2009; Lemke, 2000; Prain, Tytler, & Peterson, 2009).

Research Question 2: How do the factors which contribute to multimodal representation competency relate to improved classroom performance?

This additional research questions in this study that followed from the first research question were what factors involved in the development of multimodal representation knowledge in this genetics class that were related to the students' academic performance. From the results, there were a number of factors which emerged as being influential to the progress of student learning with multimodal representations in class. An important factor which needed to be investigated was whether multimodal representational knowledge in this genetics class had specific component which were associated with student performance more strongly than other components or if all aspects of multimodal representation are associating equally. The focused holistic rubric used to measure multimodal representational knowledge contained a number of factors which were identified as being characteristic of advancement in expertise of multimodal use. Two of the aspects of multimodal representation which could contribute to student learning which were of particular interest in this study were the number of modes used by students as well as the number of original modes created by the students. In this study, it appears that the number of modes did contribute as a major factor of multimodal representation that is associated with academic performance – at least in relation to quizzes (Table 7). As with MMR correlation scores, the number of modes did not correlate significantly with exam performance. These mixed results also suggest that neither MMR scores nor the number of modes are related to all aspects of student performance in this genetics class. Rather, multimodal representations may be more strongly associated with student performance on quizzes specifically. The combination of these results imply that the nature of the quizzes in the class are more closely related to the science tasks that the students are doing in their writing assignments than the nature of the exams. The differences in the nature f the tasks students must complete and their multimodal representation demands between quizzes, exams, and writing assignments are of particular importance to the interpretation of this study (see below).

What influence the number of original modes had on student performance was another factor that was of interest but was not found to be statistically significant for either quizzes or exams. At first, this finding indicates that it is not contributing to multimodal representational knowledge and academic performance as much as the number of modes used (Table 8). However, the number of actual original modes used by the students throughout the semester was only 17 out of 132 total modes – only about 12.8%. With so few instances of actual original modal creation by the students, it is unlikely that there was enough power in this study to detect an effect by the inclusion of original modes in a relationship to student performance. This study hypothesized that the production of original modes by the students in their writing assignments would be indicative of more advanced and complex multimodal representation knowledge than repetition of an outside source's modes in their paper (Galbraith, 1992; Prain & Waldrip, 2006). The number, type, or process of students generating original modalities will need to be investigated in order to better understand how it may be contributing to the development of science literacy in a college level genetics class.

There was also a mixed set of results for any type of mode which may have differentially affected the development of multimodal representational knowledge. This study showed that students who preferred to use diagrams in their writing assignments also had a statistical significance over other modes preferred by students although the overall difference in scores between other preferences groups was rather modest – less than 20% (Table 9). This result suggests that during multimodal representations by students those who are more likely to use diagrams are also more likely to perform better on quizzes as well. However, just as with the MMR scores and the number of modes used, the diagram results were only significant with quizzes and not exams. These results also show a trend in quizzes being more closely related to multimodal representations than exams were. Diagrams in science are extremely useful for illustrating complex phenomena and relationships among biological concepts. In the context of a college genetics class, diagrams would be extremely useful for students to describe the topics they were writing about since they can capture the complexity of relationships that the students are attempting to articulate. The other modes that were often used by students were pictures, graphs, and tables. However, pictures can only show a particular image as seen through a microscope or to the eye. Pictures may show a particular scientific result, but they tend not to show the summation of many results, ideas, or concepts. This singularity of content also extends to tables. Graphs usually show a relationship between two variables (like a scatter plot for a correlation) but are also only one set of results. Often times, diagrams are a synthesis and summation of many experiments and ideas into one cohesive representation. Diagrams are almost always used to illustrate the hypothetical model of a particular genetic phenomenon as well. Therefore, students who can regularly use and describe (accurately) the significance of diagrams to the overall conceptual task or big ideas they are asked to describe, they may have a distinct advantage over other students who are only focusing on specific aspects within the big ideas using tables or pictures.

Research Question 3: Are there any factors outside of the students' classroom writing or assessments which significantly influence, directly or indirectly, their performance?

An interesting trend that emerged from the results of the study was that all of the statistically significant correlations with MMR scores and the number of modes as well as the t-test with the diagrams modes used by students in the class were only significant with the quizzes and not the exams. Although there is a statistically significant correlation between section 2 exam scores and MMR scores, this correlation is less reliable due to its relatively small sample size (Table 9). Overall student scores are more reliable and indicate a stronger relationship between multimodal representational knowledge – as measured by a focused holistic rubric – and classroom quizzes. The nature of the classroom quizzes and exams were quite different and most likely contributed to the disparate set of results with the correlational data. The quizzes used in this study were constructed by the instructional staff (teaching assistants and the professor) with approximately ten questions per quiz that required student responses in the form of short answers, illustrations, fill-in-the-blank responses, and others. By contrast, the classroom exams were all multiple choice responses. These two assessments were extremely different in the types of tasks that were asked by the students. All of the quizzes require the students to use at least one multiple modes to answer questions whereas there was no requirement to create or explain a multiple mode by the students in the exams. When comparing quizzes and exams, the writing and cognitive tasks that are needed by the students during the composition of the writing assignments more closely resembles the quiz question tasks than the exam question tasks – which relied more upon memory recall. The results in this study suggest that quizzes which include questions that have multimodal requirements are drawing upon a similar background of experiences and knowledge as those that the students use when reading their scientific articles and/or writing their assignments.

In addition to the components which help form multimodal representational knowledge, as part of the answer to whether there were factors which influenced the development of multimodal representation in this genetics class, the differences between the sections of students. The major source of these differences arose from the instructions given to the students about the expectations of the writing assignment along with the interpretations of those instructions by the students themselves. As a result, a significant difference on the writing assignment MMR scores developed in the first writing assignment. Subsequently, the second section of students showed a statistically significant difference in their MMR scores to section 1 on their first writing assignment as well as a statistically significant increase in their MMR scores on the second writing assignment. Unfortunately, this study was not designed to investigate differences between sections and cannot determine any causal effect that may have resulted from these differences. However, there was a statistically significant difference between the sections' correlations between exam 2 and writing assignment 2 (Table 10). Unfortunately, due to the small sample size of this correlation, it is difficult to determine whether or not this relationship is true. If so, this result implies that the students of section 2 gained a benefit from increased multimodal representational knowledge between exams 1 and 2. From this finding, the impact of teacher instructions and pedagogy on the development of multimodal representational knowledge is further supported as very important to students' science literacy development (Carolan, Prain, & Waldrip, 2008).

Classroom Factors Affecting the Results

This study arose out of an interest by the researcher and professor of the Human Genetics in the 21^{st} Century to investigate pedagogical strategies to address the persistent misconceptions that were a problem in the class previously taught. The professor intended the lecture, discussions, and writing assignments to help address this problem and contribute to students' improved conceptual learning. This study began out of the interest in how well student learning and performance were developed in this newly reorganized course. Due to the professor reorganizing much of the lecture content to directly address many of the concepts which had been the source of difficulty previously, the discussion quizzes and lecture exams also complemented this redirection of instructional efforts. This approach assumes that the students in the 2010 class will develop the same set of misconceptions that the 2009 class had. There was no formative assessment of the class by the professor to determine the proportion of the class with similar misconceptions or preconceptions which overlapped with the 2009 class. So this reorganization had the effect of preemptively addressing perceived threats to student learning by the professor, but it is not possible to determine the percentage of students whose conceptions were altered as a result of the curricular changes.

With the direct approach to preventing specific misconceptions included into the course curriculum, the ability to assess the progress of students in relation to those misconceptions was included as part of their classroom assessments. The quizzes and exams were also written by the professor to determine how well the students were progressing through the class and whether the prevalence of tenacious misconceptions was inhibiting their learning. In the context of the study, collecting data on the performance of the students in relation to the pedagogical goals of the course was streamlined. The class content, assignments, and assessments were all designed by the professor or with his cooperation to address the immediate learning goals of the course. Although science literacy for the students in this study encompasses far more than could have been covered in the course assessments, the specific subset of genetics science literacy which the students were exposed to during the course of the semester was covered reasonably well by the combination of quizzes and exams in the Human Genetics in the 21st Century for the purposes of the course and this study.

The Human Genetics in the 21st Century class was a reasonable approximation of a Mid-Western college science class from its demographics. The majority of the students were white (88%) but had a noticeable amount of diversity in terms of the academic backgrounds of the students (86% non-majors). Although this class was taken by a majority of non-majors, this class was usually not taken as a general education requirement to satisfy a science course for graduation. At the particular university the study took place at, the two most common courses taken by non-majors to satisfy a science and/or biology requirement are Human Biology or Principles of Biology I. The Human Genetics in the 21st Century class then has a different distribution of students compared to larger survey classes based upon the motivation the students have to taking this class in the context of their educational program(s). From the composition of the class, there would not be a large number of extremes in the type of student participating. In large survey courses like Human Biology, there will be a very broad normal distribution of student performance due to the wide variety of students in those classes. However, with a much small section of the student body taking this particular class, the personality types and other affective characteristics may have contributed to a more homogenous distribution than found in larger classes. That type of student population would be expected to have a smaller range of student performances associated with it. Therefore, the context of the student population may have been an issue affecting data interpretation. Future investigations of multimodal representational relationships to science literacy may be able to shed light onto the possibility that student backgrounds have upon their learning.

The unintended differences between sections that arose due to instruction led to interesting results in multimodal representation during the course. The second section of the Human Genetics in the 21st Century course did not include a minimum of one multimodal representation as their instructions indicated while the first section of the students followed the directions as intended by the instructors. This difference was statistically significant in the MMR scores between the sections for writing assignment 1 (Table 2). The significantly lower writing assignment one scores also contributed to a significant increase by section 2 between writing assignment 1 and 2 (Table 5). Although causality cannot be determined from this correlational study, these differences in multimodal representational use by the students of section 2 may have contributed to some of the differences seen in their quiz 1 and exam 1 performances as well as the improvements made in their quiz 2 and exam 2 performances. Section 1 mean scores for exams are higher than section 2 but approach significance (0.05 level) for the GPA and raw scores for exam 1 and raw scores for exam 3 (Table 4). There may have been consistent motivational, experiential, intellectual differences, or other differences which could have impacted the academic scores between sections. Those factors may have existed before any class assessments due to the student composition of the sections. Unfortunately, it is not possible to accurately identify if any of these factors were responsible without further in-depth research aimed at that purpose. Furthermore, even though a correlation of either section 1 or 2 with academic performance is rather unreliable due to a restriction of range and low power, the statistically significant correlation of MMR scores from writing assignment 2 with exam 2 scores by section 2 alone are certainly consistent with the overall set of data (Table 10).

With the exception of quiz 2 scores in which section 2 students outperformed their section 1 counterparts, a consistent gap in academic and MMR score performance can be seen. With all results considered, it appears that the lower multimodal representation experience by the second section on their first writing assignment may have contributed – among other factors - to lower quiz and exam scores while their improvement on the second writing assignment may have contributed to closing the gap in performance between the two sections after the second writing assignment experience (Tables 2-4). The implications of any single modal experience in this study are impossible to determine given the limitations of the data and are further complicated by the volume of informal multimodal experiences (those not appearing in the writing assignments, quizzes, or exams) by the students in the course. The results so far are very interesting and imply that the multimodal representations, both formal and informal, are contributing to students' science learning in intricate ways.

This study focused upon the formal assessments in the course, writing assignments, quizzes, and exams, but the overall multimodal learning experiences by the students included informal interactions during lectures, discussion sections, and personal experiences outside of class time. There were at least four formal multimodal experiences the students participated in during composition of their four writing assignments (some students may have used more or less than 4). In contrast, there were as many as fourteen discussion sections throughout the semester in which students were able to participate in informal multimodal learning experiences. The impact of these informal multimodal representations may have been as important, if not more so, to the overall learning of the students than the formal experiences captured in the writing assignments and classroom assessments. Unfortunately, the correlation data cannot describe these informal experiences very well. From classroom observations, though, the informal experiences by students may have been arenas where students are able to experiment with their own knowledge sets using multimodal representations. The discussion sections met each week with the purpose of clarifying and supplementing the content covered by the lectures. Before each exam, the discussion sections also served as review sections in which the students were able to ask questions about specific areas they needed help with in preparation for the exams or to reinforce and practice the material already covered. During the discussion sections, both teaching assistants demonstrated problem-solving and illustrated concepts through multimodal representations using hand-drawn figures on a chalk board, computer presentations, and video clips (field notes). The demonstrations and explanations by the teaching assistants were very similar in format to the classroom lectures lead by the professor. Unlike lecture presentations, the teaching assistants instructed students or groups of students to work through practice problems during discussion sections. While working through problems, students were able to tentatively test their knowledge and form connections with between ideas with the support of their fellow classmates and with the scaffolding of the teaching assistants. The students and groups of students also practiced using similar multimodal representations that they saw during lecture and discussions which constituted their informal experiences. Although this study cannot argue for any educational differences between the informal learning experiences the students had during discussion sections and the formal writing assignments. However, it is possible that differences in learning experiences between formal and informal experiences did exist. These differences and how they interact to each other or to formal classroom assessments could provide fruitful research agendas in the future (see below).

The differences within the formal classroom assessments (quizzes and exams) of the class may also have had an important impact upon the interpretations of the results of this study. As described earlier in the context of the nature of the assessments, there were significant differences between the how the quizzes and exams measured student knowledge. As a result, the interpretation of the correlations between multimodal representational knowledge and either quiz scores or exam scores must be slightly different as well. The exams were all multiple-choice in format which did not limit the range of content which could be asked of the students during assessment but did limit the type of responses by the students as well as the possible depth of knowledge that they could provide in responses. Although some questions required students to have knowledge of multimodal representations which were often used in the course (ex. Determining the mode of inheritance from a pedigree), most of the multiple choice questions on exams used memory recall for students to answer the question. Most of the multiple choice questions drew upon both conceptual knowledge and specific declarative knowledge in order for students to be successful. In some cases, the wording and limited responses of multiple-choice formats of exams restricts the ability of students to construct an answer given their conceptual frameworks (see qualitative results).

In contrast, the quiz questions used a wider variety of question types and allowed a far greater depth and range of student expressions through their answers. Quizzes often had more than one type of question for each conceptual topic. For example, if the topic was meiosis, then the students had a fill-in-the blank question followed by a self-drawn diagram of a phase of meiosis and a short answer response that complemented the illustration. As a result, the students had many more opportunities to articulate their understanding on the quiz in different formats which may have better complemented their particular conceptual ecology. Of particular importance to this study, every quiz had at least one question in which students were required to interpret or create a multiple mode of representation in order to answer the question correctly. Quizzes had many more questions which required multimodal representational knowledge in order to answer questions correctly than exams. The background of knowledge and experiences from which students must draw upon to successfully complete a significant portion of the quizzes is more similar to the knowledge and experiences that students used when successfully composing a writing assignment. In this study, the writing assignments allowed students to articulate a greater depth of their knowledge in a reasonable amount of time and space while using whichever mode they chose to be the most appropriate to their understanding of the concept at the time. Although there was constraints upon the type of mode that could be used and even stronger restrictions on time and space to express themselves, the overall experience had a fair amount of overlap. Perhaps of importance in the context of student learning, the quizzes allowed students to think about certain concepts while composing responses or drawing figures during which time new connections within or between concepts could be formed as a part of the composition process. This constitutive process, if it occurred, is similar to the knowledge constitution process of writing which can explain how students create and change new ideas (Galbraith, 1992). This similarity of thinking and composition processes between quizzes and writing assignment composition does not preclude that new ideas may arise or change when students are taking exams. Since exam responses rely more heavily upon memory recall in multiple choice responses (with limited student illustrations or mathematical calculations), any new ideas or concepts that are change may arise in a different manner using different cognitive processes. Taken together, the correlations between multimodal representation scores and quizzes should have a stronger relationship due to a closer alignment of tasks and experiences by the students during their completion. Correlations between exams and multimodal representations should have a weaker relationship due to more dissimilar tasks and experiences. When the correlations between aspects of multimodality and academic performance scores are considered, neither the total student MMR scores nor the total number of multiple modes are found to be statistically significant with exam, but they were found to be significant with quizzes (Tables 5 and 6). Although the total number of original modes did not correlate significantly with either exams or quizzes, the total number of original modes during the entire semester were only 17 modes. With such a low occurrence, the power to detect an effect based upon these data is low in comparison to the MMR scores (286 total) or total modal instances (132 total). With additional data, it may be possible to continue an investigation into whether this aspect of multimodality is correlated significantly with questions similar to the quiz questions found in this study. The types of quiz questions which specifically call for multimodal representations as part of the task would be of particular importance to the research question investigating how science literacy develops in this context.

Limitations of the Study

As with any research investigation, there is no single study which can encompass all aspects of a given educational phenomenon. In this study, there are a number of limitations which must be considered before any generalization of the results or inferences of the results to the impact upon science education in college level biology classrooms or beyond. The major limitation of this research study is the lack of power in determining the relationship of multimodal representation with science literacy. This limitation is a direct result of the research design, circumstances surrounding the study, and other factors intrinsic to data analysis. In a strong experimental study, the research participants can be randomly assigned into the experimental and control groups. In a quasi-experimental study, the research participants are randomly assigned to be either an experimental or control group based upon pre-existing groups (*i.e*. classrooms). This mixed methods study used a correlational design which cannot identify causality through its results. A correlational study is valuable for identifying relationships between at least two variables, multimodal representation and academic performance. However, without the ability to make a claim of causation, this study cannot argue that multimodal representation is directly responsible for higher quiz scores and not for higher exam scores. A correlational study only has the ability to claim that a relationship exists between the two variables if it is found to be significant. This study found that significant positive correlations existed between multimodal representation scores generated through a researcher based rubric and class quiz scores. This study is limited by the design in that its argument for the relationship that exists is that multimodal representation knowledge and usage is found to occur positively along with classroom quiz scores but not exams scores.

This relationship does not necessarily imply that multimodal knowledge and representations create higher quiz scores but that the two variables share a connection such that one is often found to increase or decrease with the other. Furthermore, this relationship does not necessarily imply a directionality to the two either. That is, whatever factor or factors are related to multimodal representation scores and quiz scores, one may not always create an increase or improvement in the other. For example, improving multimodal representation scores may not always lead to an improvement in quiz scores by the students. Whatever factors are influencing the two variables may have a bi-directional nature or even have a pathway by which improving quiz scores lead to improvements in multimodal representation scores. This correlational study cannot argue for a direction to the relationship due to the unknown connections between them even though writing assignment always preceded quiz scores in the course chronologically.

There are many shared aspects of the multimodal representation rubric scores and quiz scores which could be contributing to the positive relationship. Given the relatively small number of statistically significant correlations, it is unlikely that a direct one-to-one relationship is underlying both. Without further research, the specific factors of science literacy which are contributing to both scores will remain unknown. This study argues that multimodal representational knowledge is related to the conceptual and rhetorical knowledge in science literacy. The rhetorical knowledge background the students possess is a gatekeeper for increased accessibility to new and more complicated sources of content and conceptual knowledge found in the science literature. The scientific conceptual ecology that the students possess will certainly influence both multimodal representations in their writing as well as general performance in quizzes. Conversely, the multimodal competency a student has will also act as a specific gatekeeper for content and conceptual knowledge when certain modes of representation are being used to communicate a scientific concept. The competency with which students can understand and use modes will allow them a greater depth and breadth of understanding to the content and concepts connected to those representations. Then those students who are more competent at understanding and using scientific modes in their writing will also be able to use them effectively during quizzes as well as the conceptual knowledge that they gained through their representational competency. In addition to representational competency and conceptual knowledge, there may be a host of related factors all acting in concert to contribute to the relationship which may include, but are not limited to, the general intelligence of the student, working memories of the students, motivations of the students, historical effects of personal experiences, and even simply prior learning experiences. All of these other factors may be working together, at various interconnected strengths, to influence the relationship found between multimodal representation rubric scores and quiz scores.

Perhaps just as important as the nature of the correlational design to the limits of interpretation and generalizability is the low power of the study. There were a number of issues which acts in concert together to limit the power of the study to detect a statistically significant relationship. One of the first factors to limit the power of the study was the overall class enrollment ($n = 36$). Originally, the course was predicted to have three sections of students enrolled ($48 < n < 72$). With a much higher enrollment of participants, the statistical power would to detect statistical effects would increase proportionally. An increase in statistical power from a larger participant pool would also allow this study to have detected small effect sizes as well. Fortunately, the practical significance of the study was not compromised by having only two class sections since many college classrooms have only one to two sections of students for intermediate to advanced classes at the college level.

Another important limitation of the power of this study came from the low number of instances in which formal multimodal representations were used to calculate correlations. With only four writing assignments with an overall mean of 0.91 modes per writing assignment per student, the number of total modal representations limits the power to determine how strong the relationships are between multimodality and other aspects of science literacy in the class. If there had been a third section of students or the minimum number of modes required as part of the writing assignment instructions had been increased, the increase of total modes may have increased the power to detect an effect related to the creation or inclusion of each mode as a part of the writing assignment tasks.

Although the professor of the course and both teaching assistants made a concerted effort to produce effective classroom assessments, the reliability and validity of the quizzes and exams may have been a limitation to the power of the study to detect effects between them and multimodal representation. The Kuder-Richardson (KR-20) reliability for the professor constructed class exams responses were 0.82 which indicates that the students were not given test items that were too difficult or that the distribution of scores was not too broad. The reliability for the quizzes were slightly lower at 0.699 but were administered as a parallel forms assessment. Discussion sections were held on Monday and Tuesday and students in the second section (on Tuesday) could not be given the same form of the quiz as the first second due to the possibility of discussion between sections leading to preparation for the same questions by some students. So, in order to prevent cheating by the second section students that would lead to higher scores, a similar form of the quiz was made through cooperation of the professor with both teaching assistants. The slight differences between quiz forms may have led to lower reliabilities compared to the exam which had a single form. A correlation between total exam scores by the students and total quiz scores by the students were statistically significant indicating that both academic assessments were measuring similar knowledge domains ($r = 0.487$ (32), $p < 0.01$). However, the slightly lower reliability of the quizzes also limits the power of this study to detect smaller effect sizes using correlations. Also, the correlation between quizzes and exams was anticipated to be higher ($r > 0.6$) since all were written by the professor with the input of teaching assistants and should have covered very similar sets of genetics content and concepts. This result supports the argument in this study that the quizzes and exams were not assessing the students in similar manners even though the content covered was similar.

Finally, one of the most pervasive limitations to any science education study is the limitations placed upon the data interpretation by the researcher. In the context of this study, the researcher was responsible for developing a focused holistic rubric to assess multimodal representation knowledge. This rubric was based upon previous research that has identified important aspects of multimodal knowledge (Gunel, Hand, Gunduz, 2006; Hand, Gunel, & Ulu, 2009). This information was then organized into a rubric to allow for efficient assessment of student writing assignments based upon their usage of modal representations. The rubric was refined with the aid of another researcher and checked for inter-reliability (80% agreement). However, the sheer complexity of multimodal representational knowledge is impossible to completely and accurately characterize with a focused holistic rubric. An inter-rater reliability less than 90% indicates that defining the demarcations of multimodal representational knowledge and usage can be subject to relatively high inferences. Furthermore, the specific aspects of multimodality taken from the research literature to construct the focused holistic rubric are not exhaustive and may not include critically important information that would increase its reliability and validity to this study. The researcher who constructed this focused holistic rubric had prior exposure to multimodal representation studies and constructed biases which may have limited the rubric's ability to detect important aspects of multimodality in relation to science literacy development. Researcher bias is always an intrinsic component of any research and this study is not immune from the consequences of prior experiences to the interpretation of the research data. This study did not attempt to minimize those biases but to only to acknowledge their presence (see Chapter 2).

Implications of the Study

As discussed above, there may be multiple aspects to learning which are related to multimodal representation and science literacy. Science literacy has spanned so many facets of learning in the science classroom that determining fine grained interactions has proven to be a very challenging yet productive area of educational research over many years (Yore, Bisanz, & Hand, 2003). Relationships may exist between a variety of cognitive and contextual variables that influence the development of science literacy through multimodal representation, and this study was intended to further that goal. The results of this study complement many prior studies into multimodal representation research which argue for its importance to student learning (Jaipal, 2010; Lemke 2000). Through these results and the context of the study, a number of implications can be made for science educators and researchers.

One of the most important implications from this study is the practical implementation of multimodality into the science education curriculum. The inclusion of a multimodal requirement within a writing assignment is an extremely low disruption to the overall progression of the curriculum. Instructions for writing assignment homework must be given by teaching assistants regardless of the specific subject or format. A small elaboration upon the constraints or additions to including a multimodal representation and what is expected of the students to generate a high quality modal representation took no more than 10 minutes of explanation by the teaching assistants in this study and may not consume significantly more class time in any other science classroom. The relative ease with which multimodal representations can be included in the science classroom makes its implementation a practical approach to improving science literacy compared to high tech or high interference interventions.

The relatively modest correlations seen between multimodal representations and academic performance ($r < 0.3$) indicate that the relationship between these two variables was not as strong as hypothesized by the researcher. Even though multimodal representations could be implemented into a science curriculum relatively quickly and easily, its practical significance is still an important consideration to make when curriculum is designed. Even though multimodal representations were found to be positively correlated and statistically significant with quiz scores, the lack of statistical significance with exam scores clearly shows that multimodal representations by the students cannot be used as an educational shortcut to improve science literacy. The complexity of science literacy development shows that multimodal representation is certainly required but cannot drive improvements in student learning. The fact that the number of multimodal representations does not positively correlate significantly with exam scores removes the possibility that simply by increasing the number of multimodal experiences by students that learning will necessarily follow. Therefore, this study certainly does not argue that science teachers can look to increased multimodal representations by students to serve as an allegorical silver bullet to slay the bogeyman of poor science achievement. It does provide additional evidence that the line of research into multimodal representation will continue to provide valuable insights into the nature and development of science literacy.

An unexpected occurrence in this study was the difference between sections 1 and 2 which arose due to section 2 interpreting the instructions for the first writing assignment to not have a multimodal requirement. Part of this difference arose from the teaching assistant not being as explicit in describing the writing assignment directions as the teaching assistant for section 1. Even though there was relatively little difference in the instructional time devoted to homework explanations by the teaching assistants, the clarity of the explanations was enough to lead students in both sections to interpret them differently. Furthermore, the students interpreted the instructions afterwards to mean that only one multimodal representation was required to receive full credit on their writing assignment homework. Although some students included more than one representation per writing assignment, the vast majority of students only included one multimodal representation per paper. This consistent trend shows that the students in this study only saw the practical value (from their point of view) that completing the assigned instructions lead to full credit on their homework for the purpose of their class letter grade. This study reveals that direct explanation of the purpose and process of multimodal representations during class is very important if students are to progress to the highest levels of multimodal competency and the gains in science literacy that it can lead to.

Future Directions for Research

This study used correlational data to find relationships between multimodal representational knowledge and the academic performance and a variety of associated factors. However, a strong experimental design is the most powerful in determining the effect a variable has in an educational intervention. A strong experimental design, or even a quasi-experimental design, would not have been possible given the constraints on this study. As a result, a mixed-methods correlational research design was chosen due to the request for limited interference by the professor of the Human Genetics in the 21st Century course. Since neither the professor of the course nor the researcher had control over the enrollment in either of the sections, a strong experimental design was not possible. If a similar experiment were performed in a secondary or elementary school setting in which the administration had some control over enrollment, then a strong experimental study could have been performed with random assortment into either a control or experimental group section. Also, the professor, Mr. Matthews, believed that a quasi-experimental design in which only one section received a designated number of multimodal representation requirements as part of their writing assignment would be unethical due to the difference in workloads between sections. Even if student assignments were attempted to be equalized by adding another non-modal factor to a writing assignment (additional reflection or summarization for example) so that workloads were more equal, the professor preferred not to have only one section receive only one kind of treatment. His reasoning - supported by the researcher - for equality between sections was to avoid purposefully providing only one section with a treatment that may benefit the students of one section more than another. Even if the science education research literature could not provide strong evidence that one section would receive better treatment than the other, the perception that one section might receive better treatment was enough of a difference in research design that the professor, Mr. Matthews, preferred not to allow this study to proceed with his approval as a quasi-experimental study. Due to these restrictions, a mixed-methods correlational design allowed for an investigation into the relationship between multimodal representation and academic performance without compromising any ethical considerations. However, for subsequent studies which will contribute to finer grained analyses of these factors, alternative research designs will be needed to eliminate extraneous variables and isolate dependent variables of interest (see below).

The purpose of this study was to investigate the relationship between multimodal representation and the development of science literacy in a genetics classroom. Some of the important findings in this paper revealed that multimodal representation in college level genetics classes have relationships to academic performance that are more complicated than were hypothesized. In order to contribute to the understanding of the issues in these areas and further characterize what those complex relationships consist of, additional research will be needed. From this study, a number of possible avenues to pursue fruitful investigations are possible. First of all, although a correlational design was informative for this study, it does not provide the statistical power that will be needed to identify specific effects multimodal representational factors have. Using a different research design, finer grained data analysis should be performed in order to identify the connections and directions of impact those factors have in the development of science literacy through multimodal representation.

Due to the nature of college student class registrations, a strong experimental design to investigate the issues identified would not be feasible. However, another study in which a quasi-experiment or mixed methods quasi-experimental design would be possible and will be the next logical progress of research into this area of science education. The class Human Genetics in the 21st Century will continue to be offered at the University of Iowa in the near future. The possibility to conduct research into the aspects of science literacy in this course may yield valuable insights into the subject. For this course or a closely related course, a quasi-experimental design with a control group and an experimental group could produce data which will reveal how multimodal representational use was statically significant for quiz performance and not quizzes.

Given the wide variety of factors that are still unknown which may be influencing multimodal representational knowledge development and science literacy development, an in-depth qualitative study will need to be performed. A large amount of classroom data was collected during this study that was unable to be including in the data analysis do to constraints of focus with a few exceptions. However, the importance of the classroom discussion sections and informal multimodal experiences should be a very productive path of research investigation. A very fine grained analysis of the classroom interactions and how students benefit from the informal multimodal representation experiences may also yield valuable insight into how these relationships form and how they are interconnected.

In a future mixed methods or qualitative study, the exact process of how multimodal representations are created and what benefits arise from them during writing composition should be investigated as well. This study was only able to analysis the final product of students' writing process. However, the actual learning that the student experiences during the writing process can only be known through personal interviews with the students or through a detailed analysis of the written document. These two approaches to data collection and analysis should be used in a future study but also combined with the most powerful form of research that is possible for this type of educational phenomenon, a think-aloud protocol. To completely capture how the relationship between multimodal representation and other factors emerges for the students, a think-aloud protocol in which the research will be able to observe at least one student first hand while writing an assignment with one multiple mode will allow for the richest source of information on the development of the students' learning using multiple mode representations. This research study into multimodal representation has potentially provided the foundation for subsequent research studies such as those just described to provide many fruitful sources of information for science education researchers and science educators with valuable insight into the development and nature of science literacy in American classrooms.

APPENDIX A: WRITING ASSIGNMENT INSTRUCTIONS

Reflective Writing Assignment

Each writing assignment is to be based on a **current** newspaper, magazine, journal, or internet **news** article that is especially relevant to human genetics and the topic of Mendelian genetics. Your goal for this assignment is not to give an exhaustive and detailed report, but your goal is to write a short review that covers the major points of the topic.

Example: [*A recent publication of research purported to show that first-cousin marriages were not significantly more likely to produce children with birth defects than marriages between unrelated individuals. The implication of this assertion is that such marriages should be legal and should not be advised against by genetic counselors or other professionals. To most geneticists such an assertion seems misguided at best and perhaps is just plain wrong, but the data on which the assertion is based were not published in any newspaper or magazine article available to the general public.*]

<u>Summary of the Article</u>

- Start with a summary statement indicating the main point of the article. [The article asserts *that first-cousin marriages were not significantly more likely to produce children with birth defects than marriages between unrelated individuals.*]
- Indicate the major scientific, ethical, or social implications of the main point(s) of the article. [*The implication of this assertion is that such marriages should be legal and should not be advised against by genetic counselors or other professionals.*]

<u>Historical Context or Social Context</u>

- Why is this subject important to society? [*This information could affect the future health of children born to first cousin marriages and impact social services provided to address those problems.*]
- How does this information fit with society's historical view of the subject? [*This information contradicts long-held beliefs that marriages between first cousins are likely to cause serious problems. We often read about serious genetic problems, including hemophilia, mental illness, and mental disabilities that arise frequently in the family trees of European royalty. Superficially at least these family trees indicate that marriages between first cousins could increase the probability of birth defects among their offspring.*]
- What are the assertions this article claims are important to the future of society? [*If a lot of first-cousins decided to marry and have children, this article, if incorrect, would significantly affect the number of children born with birth defects, or even with mild, hardly noticeable genetically-based differences from the general population.]*.

<u>Critique Based on Knowledge Acquired in the Course</u>

- Using the knowledge you have gained from this class, provide a brief critique of the reliability (Can you trust the information or conclusions in the article?) and validity (Is the science used in the article the best approach to addressing the problem?). Obviously, your critique should be more sophisticated by the end of the course than at the beginning of the course. You will be graded on how well you use the knowledge of the course that has been covered so far. [*Since first-cousins share one-eighth of their genes it can be shown mathematically that there should be a greater risk that first-cousin marriages will produce defects when two identical copies of the same* *defective gene are required to produce a birth defect. For example, 1/2500 North American Caucasian newborns will have cystic fibrosis; in the vast majority of cases, this is because both their parents are carriers of the disease. The frequency would increase to about 1/300 for offspring of first-cousin marriages. The question is whether this increase would be significant when measured against the background of children born with defects in the population as a whole. Without more data, this question is difficult to answer*.]

- Given the complexity of this topic, a representation of the concept you are discussing can help your explanation. Use a figure, table, graph, math equation, etc. to help you summarize what you have learned so far. Provide a brief explanation for why this representation helps summarize what you have learned about the genetics topic.

<u>Your Personal Experience of Learning the Information Presented</u>

- Provide a brief description about learning more of this genetics topic. Describe what your ideas were about the topic before taking this class. Then, describe what you learned while reading the article(s) has helped you better understand this genetics topic. Include all new opinions and conclusions you have reached about this topic based upon the new understanding you have gained. If the article were on human cloning, embryonic stem cell research, or genetically altered plants, you might say whether you thought such procedures were ethically justifiable or not and indicate the basis for your opinion. This account will be graded upon how thorough your reflection is and not upon what your opinions or ideas are (or were).

Grading: We suggest following the format given, but the relative emphasis you place on each section will depend on the article itself. You must **attach a copy of the article** in addition to its citation. Papers are expected to have proper English spelling and grammar. Particularly poorly written papers will be returned. Ultimately, the grade on the paper will be dependent on how well the paper provides the information indicated in the guidelines presented above. No late papers will be accepted without a physician's note verifying that illness was the cause. Papers will be due at the beginning of class in discussions on 9/20/10**.**

Investigative Writing Assignment

From what you have learned in class about Mendelian genetics, pose a question about what you would like to learn more about current human genetics. This question should expand upon what was presented in class. Then, find and read an article which answers your question. Provide a description of what you have learned about the human genetics question you answered. Each writing assignment is to be based on a **current** newspaper, magazine, journal, or internet **news** article that is especially relevant to human genetics and Mendelian genetic concepts.

Example: [*A recent publication of research purported to show that first-cousin marriages were not significantly more likely to produce children with birth defects than marriages between unrelated individuals. The implication of this assertion is that such marriages should be legal and should not be advised against by genetic counselors or other professionals. To most geneticists such an assertion seems misguided at best and* *perhaps is just plain wrong, but the data on which the assertion is based were not published in any newspaper or magazine article available to the general public.*]

Importance of the Question to Genetics.

- Start by stating the question you want to investigate further. [*What would be the prevalence of defects among children born in first cousin marriages?*]
- Include a simple answer to the question from the article you read. [*The article asserts that first-cousin marriages were not significantly more likely to produce children with birth defects than marriages between unrelated individuals.*]
- Indicate the major source of information found in the article which supports the answer. [*The article used research data from historical records of first cousin marriages and genetic analyses of the proportion of defective genes in the population.]*

Historical Context or Social Context

- How does this information fit with society's historical view of the subject? [*This information contradicts long-held beliefs that marriages between first cousins are likely to cause serious problems. We often read about serious genetic problems, including hemophilia, mental illness, and mental disabilities that arise frequently in the family trees of European royalty. Superficially at least these family trees indicate that marriages between first cousins could increase the probability of birth defects among their offspring.*]

Critique Based on Knowledge Acquired in the Course

- Using the knowledge you have gained from this class, provide a brief critique of the reliability (Can you trust the information or conclusions in the article?) and validity

(Is the science used in the article the best approach to addressing the problem?). Obviously, your critique should be more sophisticated by the end of the course than at the beginning of the course. You will be graded on how well you use the knowledge of the course that has been covered so far. [*Since first-cousins share one-eighth of their genes it can be shown mathematically that there should be a greater risk that first-cousin marriages will produce defects when two identical copies of the same defective gene are required to produce a birth defect. For example, 1/2500 North American Caucasian newborns will have cystic fibrosis; in the vast majority of cases, this is because both their parents are carriers of the disease. The frequency would increase to about 1/300 for offspring of first-cousin marriages. The question is whether this increase would be significant when measured against the background of children born with defects in the population as a whole. Without more data, this question is difficult to answer.]*

- Given the complexity of this topic, a representation of the concept you are discussing can help your explanation. Use a figure, table, graph, math equation, etc. to help you summarize what you have learned so far. Provide a brief explanation for why this representation helps summarize what you have learned about the genetics topic.

<u>Your Personal View of the Information Presented</u>

- Provide a brief description about learning more of this genetics topic. Describe what your ideas were about the topic before taking this class. Then, describe what you learned while reading the article(s) has helped you better understand this genetics topic. Include all new opinions and conclusions you have reached about this topic based upon the new understanding you have gained. If the article were on human cloning, embryonic stem cell research, or genetically altered plants, you might say whether you thought such procedures were ethically justifiable or not and indicate the basis for your opinion. This account will be graded upon how thorough your reflection is and not upon what your opinions or ideas are (or were).

Grading: We suggest following the format given, but the relative emphasis you place on each section will depend on the article itself. You must **attach a copy of the article** in addition to its citation. Papers are expected to have proper English spelling and grammar. Particularly poorly written papers will be returned. Ultimately, the grade on the paper will be dependent on how well the paper provides the information indicated in the guidelines presented above. No late papers will be accepted without a physician's note verifying that illness was the cause. Papers will be due at the beginning of class in discussions on 9/21/10.

Comparative Writing Assignment

Find two articles intended for different audiences about the same topic on the genetic basis for human cancers (Example: a New York Times newspaper article versus a Popular Science magazine article). Use the information in each article to provide a broader description of the genetics topic than either one would provide individually. Include a description of what you have learned about the genetics question you answered. Each writing assignment is to be based on a **current** newspaper, magazine, journal, or internet **news** article that is especially relevant to human genetics and genes and cancer.

<u>Summary of the Articles</u>

- Start with a summary statement indicating the main point(s) of each article.
- Provide a brief justification for the relative importance each article has for explaining the topic.

<u>Historical Context or Social Context</u>

- How does each article's information fit with society's historical view of the subject?

<u>Critique Based on Knowledge Acquired in the Course</u>

- Using the knowledge you have gained from this class, provide a brief critique of each article's contribution to the genetics topic. Obviously, your critique should be more sophisticated by the end of the course than at the beginning of the course. You will be graded on how well you use the knowledge of the course that has been covered so far.
- Summarize what you have learned about the topic using a figure, table, graph, equation, etc. to help combine the information from both articles. Provide a brief explanation for why this representation helps you synthesize or compare and contrast the two sources of information.

<u>Your Personal View of the Information Presented</u>

- Provide a brief description about learning more of this genetics topic. Describe what your ideas were about the topic before taking this class. Then, compare and contrast what you have learned after reading these two articles. Include all new opinions and conclusions you have reached about this topic based upon the new understanding you have gained. If you believe one article is more influential or valuable than the other, provide your justification for that here. This account will be graded upon how thorough your reflection is and not upon what your opinions or ideas are (or were).

Grading: We suggest following the format given, but the relative emphasis you place on each section will depend on the article itself. You must **attach a copy of the article** in addition to its citation. Papers are expected to have proper English spelling and grammar. Particularly poorly written papers will be returned. Papers will be due at the beginning of class in discussions on a date to be announced**.**

Grading Rubric	Points Possible	Points
Importance to Genetics	3 points	
- Question you want to explore – 1 point		
- Major source of information from the articles – 1 point		
- Simple reason for why it is important – 1 point		
Historical Context or Social Context	1.5 points	
- How does it fit with historical view of subject? – 1.5 points		
Critique based on knowledge from the course	3.5 points	
- Reliability, knowledge from course – 1.5 point		
- Representation (Figure) of the Concept – 1.5 points		
- Embeddedness of Figure – ½ point		
Personal View of Information Presented	2 points	
- Description of why you're interested – ½ point		
- Description of ideas before the course – ½ point		
- Description of how ideas have changed – 1 point		
Total	10 points	

Persuasive Writing Assignment

Each writing assignment is to be based on a **current** newspaper, magazine, journal, or internet **news** article that is especially relevant to population genetics and evolution. Your goal for this assignment is to provide a persuasive argument to someone you know (roommate, classmate, family member, etc) for why he or she should accept your interpretation of an issue related to the human population genetics. Your goal is to make a claim about the topic and provide evidence or justification for why it is the most correct answer to the problem presented. An important consideration is to use non-technical language about the science that your audience will easily understand.

Summary of the Persuasive Argument

- Start with the claim you would like to make about the topic.
- Indicate the major scientific and ethical evidence which supports this claim.
- Indicate the major scientific, ethical, or social implications of accepting the position you support.

Historical Context or Social Context

- How does this information fit with society's historical view of the subject?
- What are the assertions this article claims are important to the future of society?

Explanation of Knowledge Acquired from the Article and Class

- Using the knowledge you have gained from this class, provide a brief explanation of why the information in the article that you have read supports your position on the issue. Explain the science in such a way that someone who has not had this class will be able to understand your argument. Obviously, your critique should be more sophisticated by the end of the course than at the beginning of the course. You will be graded on how well you use the knowledge of the course that has been covered so far.

- Your audience may have difficulty in understanding some aspects of this genetics topic. Use a figure, graph, diagram, table, equation, etc to help explain your position in an easily understandable way.

Your Personal View of the Information Presented

- You should give an account of your opinion from start to finish. If the article were on human cloning, embryonic stem cell research, or genetically altered plants, you might explain how your biology classes or experiences have helped shape your opinion of the controversial topic. Be certain to explain why you have excluded alternative opinions or ideas in favor of the one you are currently supporting. In this case, the opinion itself could not be graded, but your reasoning and the thoughtfulness of your answer could be graded.
- Personify the information presented for your intended audience. Here, argue for reasons that the person you are writing to would accept the information in your article as part of your viewpoint. Write about the experiences or ideas that would be important to your audience, not just to you alone. Provide a conclusion that would be considered logical or ethical to the person you are writing to.

Grading: We suggest following the format given, but the relative emphasis you place on each section will depend on the article itself. You must **attach a copy of the article** in addition to its citation. Papers are expected to have proper English spelling and grammar. Particularly poorly written papers will be returned. Ultimately, the grade on the paper will be dependent on how well the paper provides the information indicated in the guidelines presented above. No late papers will be accepted without a physician's note verifying that illness was the cause. Papers will be due at the beginning of class in discussions next week**.**

Grading Rubric	Points Possible	Points
Importance to Genetics	3 points	
- Description of your point of view – 1 point		
- Major source of information from the article – 1 point		
- Simple reason for why it is important – 1 point		
Historical Context or Social Context	1.5 points	
- How does it fit with historical view of subject? – 1.5 points		
Critique based on knowledge from the course	3.5 points	
- Reliability, knowledge from course – 1.5 point		
- Representation (Figure) of the Concept – 1.5 points		
- Embeddedness of Figure – ½ point		
Personal View of Information Presented	2 points	
- Description of why your view is right – ½ point		
- Description of ideas before the course – ½ point		
- Description of how ideas have changed – 1 point		
Total	10 points	

APPENDIX B: SCATTER PLOTS OF STUDY CORRELATIONS

Figure B1: Scatter Plot of Multimodal Representation Scores and Exam Scores

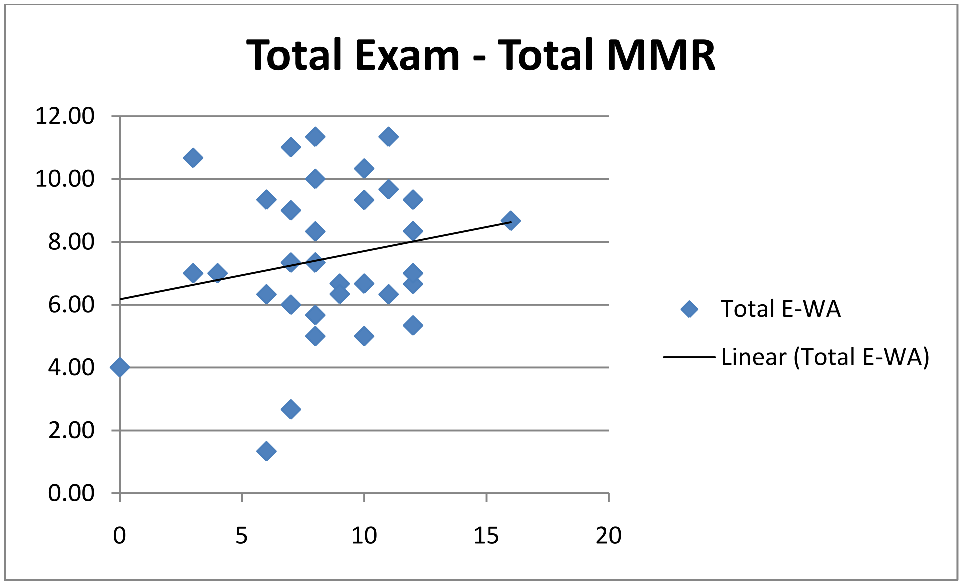


Figure B2: Scatter Plot of Multimodal Representation Scores and Quiz Scores

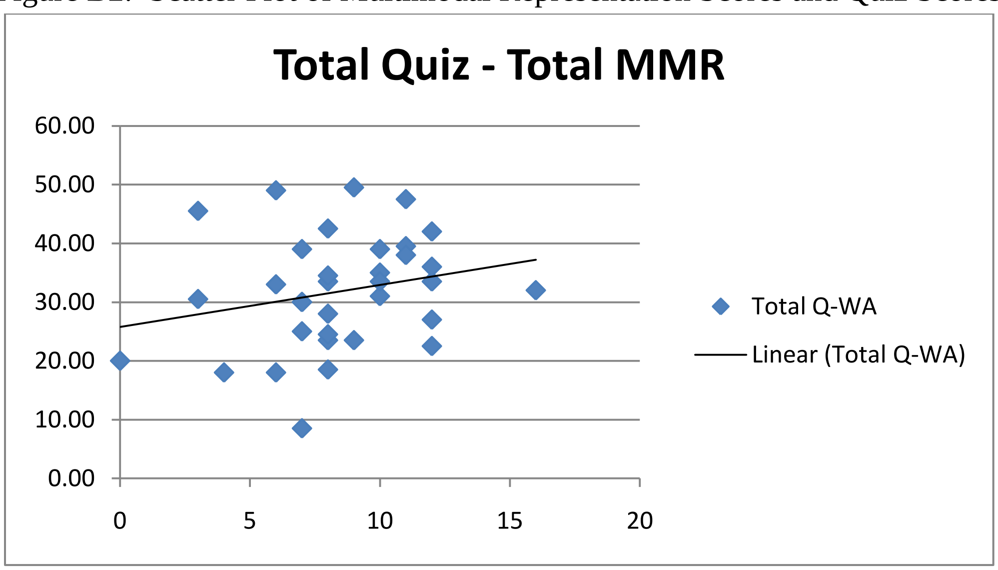


Figure B3: Scatter Plot of Total Multiple Modes and Exam Scores

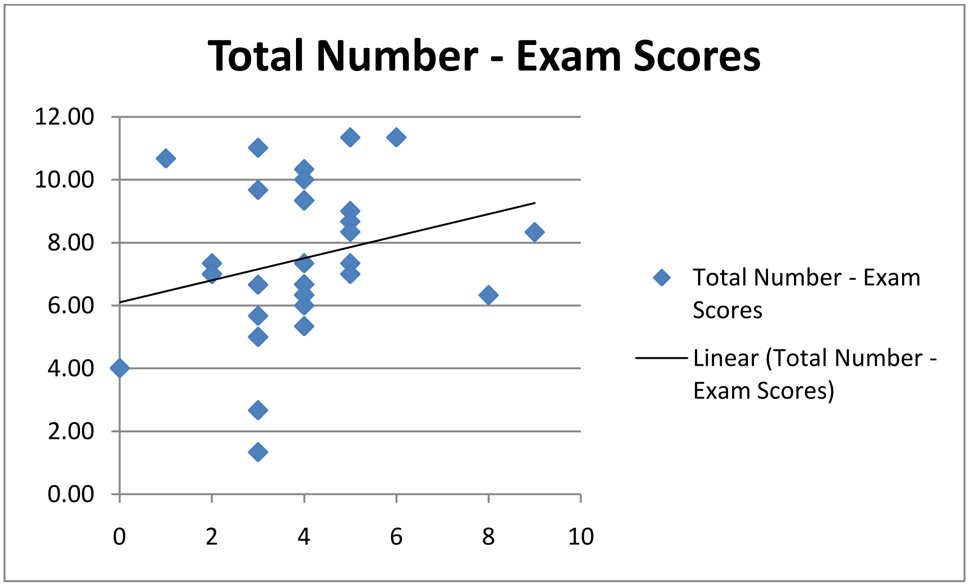


Figure B4: Scatter Plot of Total Multiple Modes and Quiz Scores

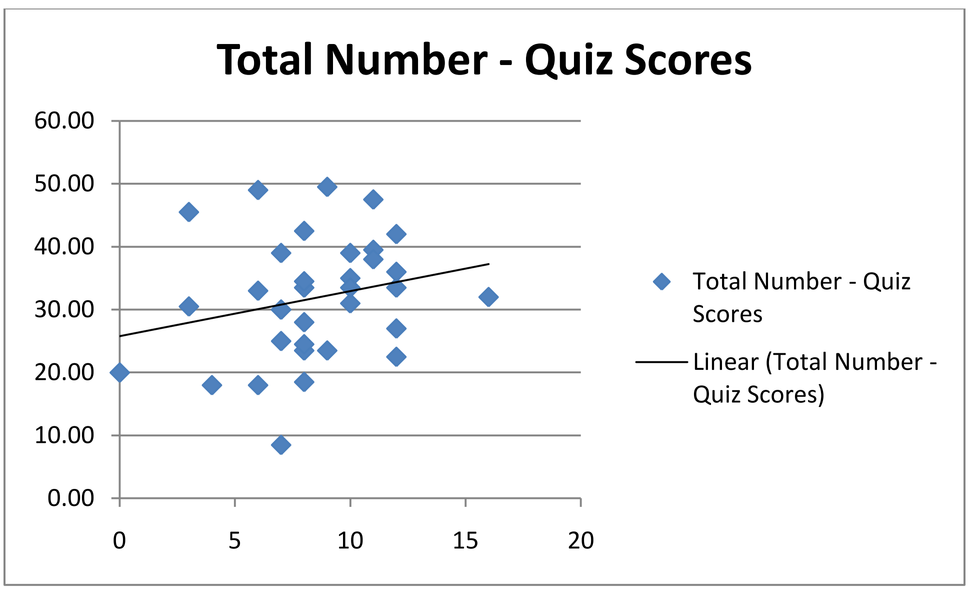


Figure B5: Scatter Plot of Total Original Modes and Exam Scores

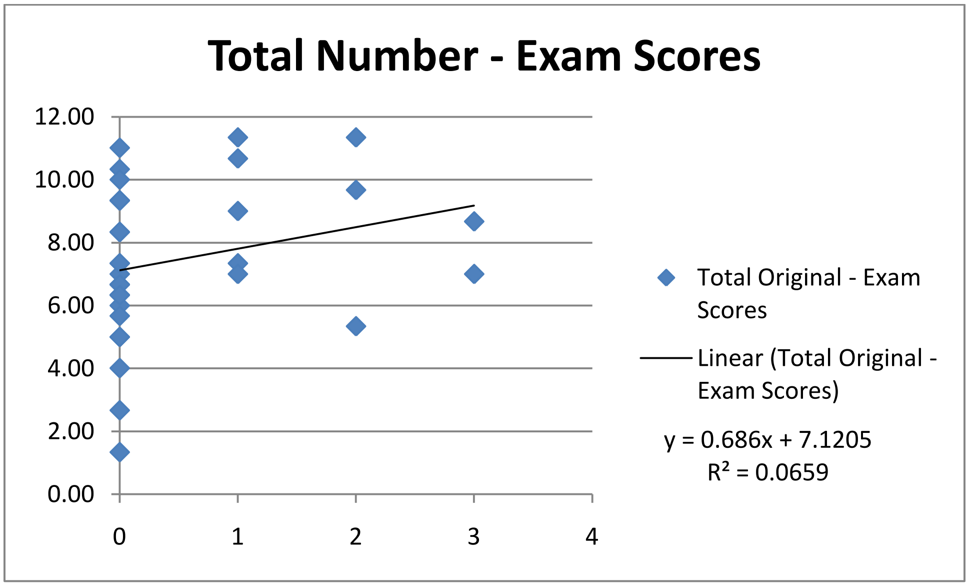
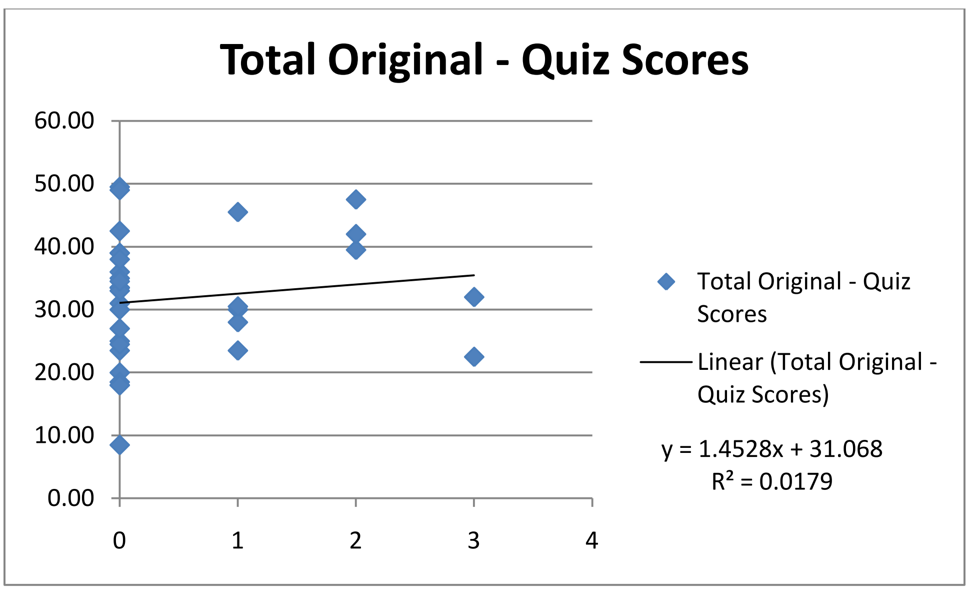


Figure B6: Scatter Plot of Total Original Modes and Quiz Scores



APPENDIX C: SEMI-STRUCTURED INTERVIEW PROTOCOLS

Instructor Interview Protocol, Semi-structured Background Questions

1. Could you tell me about your background in science and science teaching?
2. What do you see as your teaching strengths?
3. What areas do you feel are relatively weak in your teaching?
4. In what ways would you define science teaching?
5. How do you think students learn science? When your students learn science best?

Misconception Questions & Teaching Strategies (General)

1. What concepts in (a topic) do you believe are the most important for your students to understand by the end of the instruction of this topic? Why?
2. Reflecting on your experience of teaching this topic (photosynthesis or heredity), what kinds of student misconceptions associated with this unit have you noticed?
3. How do you challenge the misconceptions?
4. How do you know when your students have misconceptions? What strategies do you use to understand students' understanding in this topic?
5. How do you know when your students understand a concept?
6. What do you usually consider when you plan a lesson? (students' prior knowledge of the topic, learning difficulties with specific science concepts, etc.)

Interview Questions in Combination with Observation

1. Could you briefly describe today's lesson?

2. What subject matters or concepts do you expect students would have difficulties with today? Why do you think so?
3. What kinds of students' misconceptions associated with this lesson have you noticed? How would you help them correct the misconceptions?
4. What kinds of things do you take into consideration in planning this lesson?
5. How will you be able to know whether your students understand the concepts you try to teach today? What evidence are you looking for that students have been successful in addressing the goals for the lessons?

Student Interview Protocol, Semi-structured

1. Was the writing you did beneficial or useful?
2. Did writing change your understanding?
3. Does writing help you learn?
4. Was writing to a different audience helpful?
5. Did you find drafting useful?
6. Was feedback helpful?

Background Questions

1. Could you tell me about your background in science and school?
2. What do you see as your academic strengths?
3. What areas do you feel are relatively weak in your education?
4. In what ways would you define science?
5. How do you think you learn science best?
6. Have there been any writing activities that have helped you learn science?

Learning Environment Resources

1. What concepts in this class do you believe are the most important for you to understand by the end of the semester? Why?
2. Reflecting on your experience science classes, what kinds of misconceptions have you noticed about your own knowledge?
3. How do you study for an exam and/or quiz?
4. What strategies do you use when working on homework?
5. How do you know when you really understand a concept?
6. What would you like to have in a science class that helps you learn?

Past Experiences/Historical Factors

1. What is the best experience you have had learning science?
2. Who was your favorite science teacher?
3. How has learning science affected your life?
4. What aspects about learning science do you like the least?
5. What motivated you to take this science class?
6. How do you think your education has prepared you to be scientifically literate?

Contextual Factors

1. What characteristics of a science teacher do you believe are necessary to be a successful teacher?

2. Has there been anything from outside of the science classroom that directly influences your learning in the science classroom, for better or for worse?

Views of the Nature of Science

1. Is learning science just about learning facts?
2. Do you could carry out a science experiment by yourself?
3. Are scientists ever wrong?
4. What is the difference between a hypothesis, a theory, and a law?
5. Are scientists objective?

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