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Exploring How Middle School Students' Epistemologies in Practice Change Across Time with Varying Content Areas And Knowledge Product Contexts

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EXPLORING HOW MIDDLE SCHOOL STUDENTS' EPISTEMOLOGIES IN PRACTICE CHANGE ACROSS TIME WITH VARYING CONTENT AREAS AND KNOWLEDGE PRODUCT CONTEXTS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Mackenzie E English ENTITLED Exploring How Middle School Students' Epistemologies in Practice Change Across Time with Varying Content Areas And Knowledge Product Contexts BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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Abstract

Recently, the National Research Council developed *A Framework for K-12 Science Education* (NRC, 2012), to support a new vision of science education. The *Framework (2012)* focuses on three integrated dimensions--disciplinary core ideas, crosscutting concepts, and scientific and engineering practices which is different than traditional ways of learning science. I focused on students' engagement in scientific practices, attention to epistemological practices (EIP) that guide students' construction, evaluation and revision of knowledge products. I examined how students EIP's changed over time and across contexts with respect to different knowledge product types (models and explanations). I present data from 103, 6th grade students attending two Midwest suburban elementary schools. I collected written embedded assessments and conducted semi-structured interviews. The Science Practices Group has identified four epistemological considerations that comprise students' epistemology in practice—type of account, generality, audience, and justification. I found that students exhibited growth for one of the four epistemological considerations. Students increased from descriptive to more mechanistic explanations (type of account) for modeling and explanation construction. Audience, generality, and justification epistemic considerations decreased over time or remained constant. These findings may suggest that supports from classroom instruction norms and curriculum enactment may affect use of these epistemological considerations in the classroom. Overall, I do see promise in using the epistemological considerations as supportive tools for students when making sense of the practice and engaging in meaningful science learning.

Keywords: epistemology, scientific practices, modeling, middle school

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Scientific literacy is the knowledge and ability to understand the basic ideas about phenomena in the natural world and the scientific processes that define those phenomena that allow someone to make knowledgeable decisions on both public and personal issues (American Association for the Advancement of Science (AAAS), 1993; National Research Council (NRC), 1996). The next generation of students will require this scientific literacy to effectively participate in public discussions and cope with changes that will occur in the world. As the body of scientific knowledge increases exponentially in size and complexity, how we provide that information to our students must continue to be reevaluated. It has been at least 15 years since we developed the *National Science Education Standards* (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993) a reform standards-based initiative to push scientific literacy in science classroom teaching. These efforts identified three principal components essential for science literacy—scientific knowledge, scientific inquiry and the nature of science. These initiatives provided more attention to teaching inquiry and nature of science, yet still in the classroom there continues a greater focus on learning science as a body of knowledge, detached from scientific inquiry and the nature of science.

Most recently, the National Research Council developed *A Framework for K-12 Science Education* (NRC, 2012), to support a new vision of science education by providing enriched science teaching and learning experiences. The *Framework (2012)* also provides the foundation for the development of *the Next Generation Science Standards (NGSS)* (NRC, 2013). The NGSS are a set of K-12 science standards created through the collaboration of 18 national and international scientists and science educators.

The *Framework (2012)* is innovative and different than traditional ways of learning science. Traditional ways of learning science typically focus on memorizing a body of knowledge and then separately learning scientific processes or skills. Whereas the *Framework (2012)* focuses on three integrated dimensions--disciplinary core ideas, crosscutting concepts, and scientific and engineering practices. Students learn core scientific ideas over time, progressing toward more sophisticated understandings. At the same time, students learn practices such as modeling and cross-cutting concepts are used to understand and build these core scientific ideas. The *Framework* (2012) supports a more integrated approach similar to real world science and engineering methods of building knowledge.

Disciplinary Core Ideas

The disciplinary core ideas are divided into the different subject areas of physical science, life science, and engineering and technology (NRC, 2012). The area of physical science includes the subjects of physics and chemistry. The core principle of the physical sciences is to examine particle and light movement, force and momentum, and how and why substances are different. The physical sciences serve as a foundation for understanding the other sciences by demonstrating to students the cause and effect nature of all physical and chemical principles (NGSS, 2012).

The life sciences core idea involves examining all systems of life ranging in size and scope from single cells to the biosphere. A core principle is that all living organisms are related through evolution and that the diversity of life found on Earth is due to these evolutionary processes (NRC, 2012). Even though there are several million species of organisms identified to date, they are all influenced by the same processes at the genetic or cellular level. This core idea focuses on helping students understand concepts and processes ranging from cellular structure and function, to ecology and evolution.

Earth and space science (ESS) core ideas involve terrestrial phenomena as well as phenomena involving the solar system/universe. Those phenomena range from the microscopic (minerals) to the largest of objects (stars and star systems). ESS is made up of components first laid out by the other sciences; i.e. cause and effect relationships of the physical and life sciences. For example, the physical sciences (physics) provide an understanding of how forces are enacted on, or by, the Earth and moon. The physical sciences (chemistry) also provide a look at the chemical composition and structure of the Earth and its physical features. Understanding the biological sciences is essential to comprehending ESS core ideas because the Earth is a biological planet.

Crosscutting Concepts

Concepts in science rarely, if ever, are limited to only one discipline or subject. Most concepts have components that influence multiple subjects. These concepts are known as crosscutting concepts and each of the concepts can stand alone or work with other concepts. As outlined by the *Framework* (2012), these concepts include; (1) patterns, (2) cause and effect, (3) scale, proportion, and quantity, (4) systems and system models, (5) energy and matter, (6) structure and function, and (7) stability and change.

The idea behind crosscutting concepts has also been known as "themes" (AAAS, 1989; AAAS 1993), "unifying principles" (NRC, 1996), and "crosscutting ideas" (*Science Anchors Project*, 2010) in previous works. Crosscutting concepts should be included continuously in all core idea instruction to reinforce student understanding of interconnectivity. Examples of these concepts include patterns seen in DNA, the cause and effect of introducing new species into an ecosystem, and how increasing the temperature of a gas causes it to spread around a room faster.

Scientific Practices

For a student to understand and gain scientific knowledge in the classroom, they must have an understanding of the scientific practices. Scientific practices represent the social and scientific construction, evaluation, and communication of scientific knowledge (Bell & Linn, 2000; Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Osborne, Erduran, and Simon, 2004; Duschl, Schweingruber, & Shouse, 2007). It is important for students to learn science in the same way that scientists learn and construct scientific knowledge. Science education research efforts over the last decade have shown that scientific practices are significantly useful for student learning (Veerman, 2003; Lehrer & Schauble, 2006; Duschl, Schweingruber, & Shouse, 2007; Schwarz et al., 2009; Berland & McNeill, 2010). According to the *Framework* (2012), there are eight main practices required for student learning. When referencing science only, the eight practices described by the *Framework* (2012) include asking questions, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information.

These practices help students to obtain firsthand knowledge and views about how scientific knowledge is developed. These practices work together to give a better understanding of how science works at the professional level. Science does not work on a set of procedures or steps, such as the "scientific method" requires, but instead it builds on ideas—making sense of findings, using results to develop models, arguing competing explanations, and reaching consensus as they build knowledge.

For the purposes of this study, we focus on three specific scientific practices—modeling, explanation and argumentation. This is done based on an understanding that the remaining five practices occur within the three presented (Reiser et al., 2012; NRC, 2012). When examining a real world scenario, one can start by questioning and investigating the scenario, create a model or explanation by analyzing and interpreting data, and argue with peers to convince them that their model or explanation is correct by using evidence found during an investigation. These models and explanations can prompt new questions that in turn are questioned and investigated (NRC, 2012).

Modeling. Scientific modeling refers to the practice of construction, testing, and revising a model (an abstracted system containing key features) that could explain or predict the reasoning of multiple visible phenomena (Giere, 1992; Harrison & Treagust, 2000, Schwarz & White, 2005, Passmore, Stewart, & Cartier, 2009, Schwarz et al., 2009). Models fall under two categories, conceptual or mental models and expressed models. Conceptual or mental models represent someone's internal representation of the phenomena, while expressed models represent someone's idea model (Harrison & Treagust, 2000, Schwarz et al., 2009, Lehrer & Schauble, 2012, NRC, 2012). Models are a tool created to help someone explain what is occurring in a phenomenon and contain four main elements; these include construction, use, evaluation, and revision of their models (Duschl, Schweingruber, & Strouse, 2007, Schwarz et al., 2009). The models construction and use help students to understand the explanatory mechanisms that occur within a phenomenon (Carey & Smith, 1993, Schwarz et al., 2009). These are used to help understand a system or phenomenon, develop new questions and explanations, and communicate ideas to people (Nercessian, 2008). Previous studies have shown that younger students progress from the creation of illustrative models to abstract, explanatory models (Lesh & Doerr, 2000; Schwarz & White, 2005; Stewart, Cartier, & Passmore, 2005; Lehrer & Schauble, 2006; Schwarz et al., 2009).

Explanation. Scientific explanations are verbal representations of the mechanisms that are occurring in a phenomenon. They contain the development of claims and reasoning that provide an account of how and why a phenomenon occurred (Southerland et al., 2001; Sandoval & Reiser, 2003). The mechanisms are based around scientific theories, or the large amounts of knowledge and evidence collected about a phenomenon. The best explanation for a phenomenon is often decided by how well it fits the known evidence, its simplicity, and whether it is easy to understand (NRC, 2012). Scientific explanations contain a *claim* about what is occurring in the phenomenon, *evidence* to support the claim, and *reasoning* to connect the claim and evidence together (McNeill, 2011). Students often struggle with constructing explanations, especially reasoning, in the early learning process. Some respond, “I don’t know” (McNeill, 2011). This may occur because the phenomenon or a concept is too complex. It has been shown that when complicated phenomena are broken down into parts, students are able to better understand them and create explanations (Windschitl & Thompson, 2010, Windschitl et al., 2012). This supports using a framework for explanations to improve student growth.

Argumentation. Students can use their created models and explanations to persuade, build upon, or argue with others about how to best explain the phenomenon. This argumentation refers to the practice of peer persuasion and consensus building of scientific claims (Bell & Linn, 2000; Driver, Newton, & Osborne, 2000; Sampson & Clarckson, 2008; Berland & McNeill, 2010, Evagorou & Osborne, 2013). It can also show the weaknesses and limitations of the original knowledge product and allow for the construction of the best or most complete knowledge products within the classroom. This is accomplished by presenting the evidence and rationale of the reasoning to persuade others of the effectiveness and correctness of one's knowledge product (Evagorou & Osborne, 2013). Previous studies have shown construction of argumentation between teachers and students can lead to greater class discussions. Teachers or more knowledgeable peers were able to use everyday situations as prompts to start discussions with the students. Over time, these discussions developed into student lead discussions where students created their own scientific argument (Erduran, Simon, & Osborne, 2004; Quintana et al., 2004; McNeill, 2011).

Theoretical Framework

I believe that there is an important relationship between the real world and knowledge products created by individuals. This relationship is adapted from the *Framework's* (2012) representation of the practices and a synthesis of numerous representations of scientific endeavors (Duschl, Schweingruber, & Strouse, 2007). The practices described by the *Framework* (2012) can be described as interrelated and can allow for investigating questions about the world (Figure 1). These interrelations allow for a flow of investigations and questions that can lead to an expansion of student scientific knowledge (NRC, 2012; Reiser et al., 2012). The construction of scientific models and explanations require the individual to analyze and interpret data and explain the phenomenon. The model or explanation can then be applied to ask questions about the world so the phenomena can be investigated. Both scientific models and explanations are seen as tools used to understand the processes of phenomenon, whether by diagrammatic model or scientific explanation (Sandoval & Reiser, 2003; Southerland et al., 2001, McNeill, 2011, Duschl, Schweingruber, & Strouse, 2007, Schwarz et al., 2009). These tools, called knowledge products, are a way for the students to interpret the data collected from inquiry driven, project-based curriculum. Students can use these knowledge products to convince others of their ideas about the phenomenon or use them to refute other knowledge products. This idea of argumentation between peers can be used to create new knowledge products or refine previous ones based on critiques and new data that are presented during the argumentation.

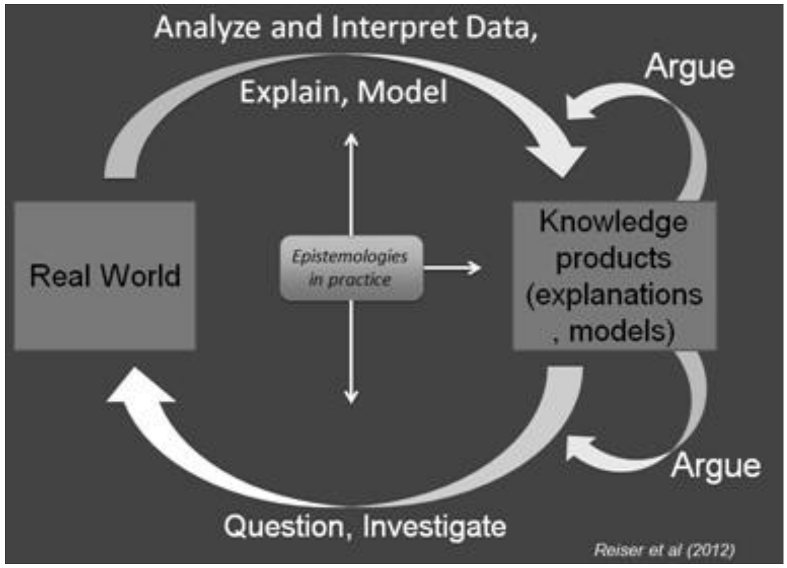

Figure 1. Adapted framework diagram showing interrelationship of the NRC's practices.

Epistemologies in practice. In addition to this framework is the use of epistemology, which is the understanding of the sources, limitations, and validity of knowledge gained (Cawthorn & Rowell, 1978; Bang & Medin, 2010, Russ, 2014). Epistemology for science allows for one to construct knowledge and understand phenomena (Russ, 2014). Throughout the observed practices of modeling, explanation, and argumentation, there are epistemological ideas that are used by students as a way to guide construction, evaluation and revisions of their knowledge products. The Science Practices Group refers to these epistemological ideas as *epistemologies in practice* (EIP). In using the term *epistemologies in practice* I mean to emphasize that the epistemologies guiding student work are a combination of ideas *and* action.

The epistemological aspects that I emphasize share three components. First, I emphasize those aspects that are most likely to influence how students construct and evaluate scientific knowledge products— the epistemological aspects most likely to be applied in the students' scientific practice— and those with which these students are most likely to be able to engage. In addition to their utility in the classroom, the epistemological aspects which I focus on are consistent with and have grown out of earlier work that identified particular features which distinguished between levels of student performance when modeling (Schwarz et al., 2009; Schwarz et al., 2012), and considerations in argumentation (Berland, 2011; Berland & Reiser, 2009, 2011). Furthermore, the aspects of students' epistemologies are among those that have been identified as important in knowledge building in the discipline (Abd-El-Khalick et al., 2004; Duschl, 2008; Lederman, 2007).

Based on their utility, presence in student work, and scientific importance, we have identified four epistemological considerations that comprise students' epistemology in practice. These epistemological considerations are questions or issues that students could consider while engaging in the work of scientific knowledge building to guide construction, evaluation, and revision of knowledge products (models and explanations) (Table 1). The first question students ask is *what kind of answer should my knowledge product provide?* This is the aspect of *type of account* and it includes the cause and effect relationships and the explanatory process of the phenomenon someone is observing. Responses can range from descriptive accounts of the causal relationships to a more sophisticated/scientific response. The next question asks *how does this knowledge product relate to other scientific phenomena and ideas?* This addresses the aspect of *generality* and relates to how someone is able to relate their knowledge product to other knowledge products and related phenomena. Responses vary from being very specific, focusing on only one phenomenon, to addressing a broad range of related phenomenon.

The third question asks *who will use my knowledge products and how?* This is termed the epistemological consideration of *audience*. This consideration identifies the student's target audience and how persuasive their knowledge product is for that audience. Responses vary from having no apparent audience (looking more for a correct answer), to creating knowledge products, to evaluating other proposed knowledge products. The final question is *how do I justify my knowledge products?* This represents the epistemological consideration of *justification*. This epistemological consideration is based on the student's understanding of where the ideas and the support of those ideas for the construction of knowledge products come from and how the knowledge products reflect those ideas. The responses vary from focusing on accuracy and authoritarian figures (teachers), to a more sophisticated view of the empirical and theoretical support.

In our emphasis on the students' epistemological considerations, we do not mean to negate the importance of content knowledge or practical skills. Instead, we see that an individual knowledge product (i.e., an explanation about why a particular population is decreasing or a model of predator/prey relationships) will improve as a result of students' increased content knowledge (i.e., understandings of relationships between organisms) their frequent practice of relevant skills (i.e., identifying and analyzing data), and through their application of epistemological ideas that align with the work of the scientific community (i.e., attention to evidence while striving to understand underlying mechanisms). Each of the considerations represents different aspects of the knowledge products and therefore has been laid out in greater detail in the following paragraphs. These show what each of the considerations represent and what they are observing.

Table 1

Epistemological considerations to which we attend in the students' epistemologies in practice

Epistemological Consideration	**Possible Ways to Address this Consideration**
What kind of answer should our knowledge product provide? (Type of Account)	• Our knowledge product should describe what happened. • Our knowledge product should identify a relationship between components. • Our knowledge product should explain how or why something happened (a mechanism).
How does our knowledge product relate to other scientific phenomena and ideas? (Specificity / Generality)	• Our knowledge product should be specific so that they can only be used to explain specific, targeted situation. • Our knowledge product should be consistent with the science ideas and experiences I already know • Our knowledge product should be general so that they can be used to explain a range of scientific phenomena.
Who will use our knowledge products and how? (Audience)	• Our knowledge product is to show the teacher our understanding. • Our knowledge product is something I will use to learn new ideas. • Our knowledge product is something others could use to understand • Our knowledge product should convince others of the validity of our thinking.
How do we justify our knowledge products? (Justification)	• Our knowledge product doesn't need to be justified because it is right or wrong. • Our knowledge product should be justified using authoritative information. • Our knowledge product should be justified using non-authoritative information (i.e., empirical data, sourced ideas, logical accounts etc.)

Type of account. When creating a knowledge product, students may wonder what should be included and what counts as an answer to a scientific question. These questions are part of the epistemological consideration referred to as the *type of account* and include how and why a phenomenon occurs. An account being the statement that explains the scientific phenomenon (Jin and Anderson, 2012). The type of account can be used to address the cause and effect relationships and the explanatory processes found within a phenomenon (Windschitl, 2008; Passmore, Stewart, & Cartier, 2009). Studies have shown that students enter the classroom with the ability to use scientific resources and to think scientifically. Studies also suggest that students at all levels should be given scientific examples that are rich with mechanistic subject matter to allow those students to practice reasoning and explanatory process building (Siegler, 1996; Hammer, 2004; Duschl, Schweingruber, & Strouse, 2007; Russ et al., 2008).

Possible ideas as to the nature of science products range from valuing details and detailed descriptions, causal relationships between the parts of the phenomenon, and demonstrating a more scientific goal of articulating a step-by-step causal account. For example, when focusing on detailed descriptions, students may describe how they smell the perfume worn by someone across the room because the smell moves as the result of an outside force (like wind), giving no mention of microscopic scale or particle movement (invisible components). When students move toward causal relationships between components, they describe that odor molecules move on their own towards the nose. Here, students point out the invisible components and possible interactions, but do not discuss a sequence of *how* they move across the room. Students may show a more sophisticated mechanistic explanation by articulating a step-by-step causal account, including aggregating all components together. For instance, students explain how the odor particles bounce off one another and the other particles in the air and eventually spread out across the room and eventually to the nose.

Generality. Generality relates to the students understanding of how their knowledge products relates and applies to a wide variety of other phenomena or domains (Schommer & Walker, 1995; Schommer-Aikins, Duell, & Barker, 2003). When students see a phenomenon occur, there are two primary ways that the student could view it. The first is very specific with the student seeing the individual part and how it explicitly relates to the phenomenon. In the second way, the student may relate the phenomenon or parts of it to something else they have seen or another idea that follows the same guidelines. Following these ideas, students may ask if this created knowledge product can be related to other scientific phenomena or ideas. These ideas have been acknowledged by others that have shown how students can have positive correlations of epistemology when looking at generality (Spiro, Coulson, Feltovich, & Anderson, 1988; Schommer & Walker, 1995; Schraw, Dunkle, & Bendixen, 1995; Schommer-Aikins, Duell, & Barker, 2003).

Possible student ideas vary from specificity to the original idea, to a more sophisticated and general product that relates to a broad range of phenomena. The least general of ideas, fall into the category of accuracy and making the knowledge product specific to only the current phenomena. Subsequent responses may tend towards more generality which demonstrates the students' responses progressing into partial generalization of parts of the phenomena. Finally, students may grasp the idea of generality by completely generalizing a part of, or the entire, knowledge product.

Audience. When a student creates a knowledge product, there may or may not be an intended target for their product. The target is typically who they believe will be able to use their product to the fullest. This idea of a target or who can use the knowledge product is the epistemological consideration of audience. Students should be able to use their knowledge product to show and convince others of their ideas or to use their products to rebut what another student believes (Bielaczyc & Collins, 1999; Engle & Conant, 2002; Michaels et al., 2008; Resnick et al., 2010).

This epistemological consideration can show a broad range of student ideas or responses for who they believe will be able to use their knowledge product. Students' reflective practices range from being focused on the classroom goals, viewing and working on knowledge products as (in)correct facts with no obvious audience, to creating and revising knowledge products that can be evaluated against competing ideas that must be resolved by the knowledge building community. The latter can be seen when students design knowledge products that explicitly respond to the needs of their audience.

Justification. During the creation of knowledge products, students must use knowledge gained from previous activities and encounters to create their product. This knowledge can be seen explicitly or implicitly in the knowledge product and reflects the students understanding of the account (Sandoval & Millwood, 2005). These activities and the knowledge gained are part of the epistemological consideration of justification. Students can use justification in coordination with their causal claims to support or refute knowledge products (Driver, Newton, & Osborne, 2000; Sandoval & Millwood, 2005). Previous studies have shown a range in student responses when presenting different knowledge products. This range varies from students presenting claims with no justification (Kelly et al., 1998; Jimenez-Aleixandre, Rodriguez, and Duschl, 2000), to the full use of justification as support for or against claims (Duschl, Schweingruber, & Strouse, 2007; McNeil, 2011).

Students' ideas vary exhibiting decisions ranging from focusing on accuracy and authoritarian support (i.e., teacher) to emphasizing empirical and theoretical supports. For example, when discussing how smells travel across a room, a student may bring up past experiments that explained how gasses behave in different environments; i.e. the compression and expansion of gasses to form higher and lower pressure systems.

Study Focus

This study examines the development and use of epistemologies in practice (EIP) in the classroom by the students during one year of science class. Using the theoretical framework and practices described above, I use an inquiry-based curriculum and assessments to test the development of the student's EIPs. Specifically, I look at how each of the epistemological considerations compare to one another within the different knowledge products and how each of the considerations change over the course of a year. I specifically explore the following research question: How do students' EIPs change over time and across contexts with respect to different knowledge product types (scientific modeling and explanations)? How do their epistemological considerations develop?

Methods

Study Contexts and Participants

Data collection was conducted in two Midwest suburban elementary schools within the same school district over a one-year period. The school district was approximately 0.9% African American, 2.5% Asian, 2.1% Hispanic, 92.3% White, and 2.2% Multi-Racial. Approximately 4.7% of the students were considered from an economically challenged family and 10.8% of the students had a disability.

Two teachers participated in the study. Both teachers used the provided curriculum for one year prior to the collection of data. This allowed the teachers to become familiar with and better understand the curriculum and the practices prior to the study. School H consisted of 47 students with one teacher, Mr. G, who taught 4 self-contained 6^{th} grade classes (Table 2). School S consisted of 56 students with one teacher, Mrs. E, who taught 5 self-contained 6^{th} grade classes (Table 2). In total, 103 elementary students participated in this study.

Table 2

Distribution of students' and classes between the two schools

School H	**Number of Classes**	**Number of students**
Mr. G	4 self-contained 6^{th} grade classes	47 Students
School S		
Mrs. E	5 self-contained 6^{th} grade classes	56 Students

Curriculum Context

In this study, the teachers were provided with a set of reform-based science curriculum materials. The curriculum, *Investigating and Questioning our World through Science and Technology* (IQWST) (Krajcik, McNeill, & Reiser, 2008; Reiser et al., 2003; Shwartz et al., 2008), is a comprehensive project-based, grades 6-8 middle school curriculum that promotes student understanding of key scientific ideas and practices by coordinating instruction across units within and across each grade level. The curriculum is composed of four interconnected science units covering physical science, chemistry, life science, and earth science.

During this study, only certain units from the IQWST curriculum were enacted by the two schools. The units include one from the 6^{th} grade curriculum and one from the 7^{th} grade curriculum. Over the duration of this study, the two schools enacted two of the provided curriculum. Both School H and School S enacted the 6^{th} Grade Chemistry unit and the 7^{th} Grade Biology unit (Table 3).

Table 3

The units of the provided curricula enacted by each school over the two years

School H	Aug. 2012- May 2013	
Grade 6	IQWST 6 Chemistry (Particles)	Aug. 2012 – Dec. 2012
	IQWST 7 Biology (Cells, Body Systems)	March 2013 – May 2013
School S	**Aug. 2012- March 2013**	
Grade 6	IQWST 6 Chemistry (Particles)	Aug. 2012 –Oct. 2012
	IQWST 7 Biology (Cells, Body Systems)	Jan. 2013 – March 2013

In the 6th grade Chemistry unit students determine how particles move across distances through the air. Students begin by learning how odors move from a source into the air and what must occur for this to happen. This is determined by observing that odors are made of molecules which contain mass and volume. They then learn how the odor particles are the same molecules from the source, how different odors are made of different particles, and the properties of air (compression and expansion). Students observe the properties of different odors and use experiments to determine the different properties odors have. They finish the unit by figuring out how temperature will affect the rate of speed of the particles. Students determine these goals by conducting experiments showing how temperature affects the rate of dispersal by heating and cooling odor sources. Throughout the unit students created models to show the different properties of molecules in the air.

The second unit enacted was the 7th Grade Biology unit. This unit focuses on the different organ systems within the human body, with emphasis on how energy gets to cells. Students start by learning about cells and what they need to function and students observe onion cells and osmosis. They then follow the process of how food is broken down by the digestive system, how nutrients are then absorbed by the circulatory system, and then moves along with oxygen from the respiratory system to the cells to allow them to function. Students create "cells" to help determine what kinds of food are able to pass through the cell membrane and what cannot. Experiments and observations on the conditions of the stomach acid and use of the food by cells were enacted so students could create knowledge products of the results. The second half of the unit focuses on cellular growth and repair (skeletal) and how the body maintains itself during exercise (circulatory and respiratory). Students made observations of bone structure and conducted experiments measuring heart and respiration rates. The final portion of the unit includes multiple body systems together. Students determine how the different systems work together and how they keep the body functioning. To show how the different systems interact, students created scientific explanations.

Each of the enacted units from the IQWST curriculum focus on one or two knowledge products (modeling or explanation) being constructed, evaluated, or revised. The practice of argumentation is found within all units as a basis for persuasion and student interactions within the units. The particle movement unit (6 Chemistry) focuses on the practice of modeling (Table 4). The body systems units (7 Biology), has components of both modeling and explanations, but focuses mostly on the practice of explanation.

Table 4

The knowledge products focus for each of the provided units

School H	6 Chemistry (modeling)	7 Biology (models and explanations)
School S	6 Chemistry (modeling)	7 Biology (models and explanations)

Data Sources

Multiple forms of assessment data have been collected to construct profiles of each of the students individually, and as a class. I collected both written embedded assessments and semi-structured student interviews.

Embedded assessments. I used embedded assessments within the units to allow for direct analysis of the practices during the actual enactment of the content. I administered two embedded assessments, one at the beginning and one at the end of each unit to capture growth during this time. Each embedded assessment targeted student understandings about the four epistemological considerations around a student constructed knowledge product within the unit (Appendix A-C). The embedded assessment asked students to construct a knowledge product and then answer a question specific to an epistemological consideration. I gave both schools the same four embedded assessments throughout the units (Table 5). Time between the assessments was widely spread to allow enough time for potential growth in the EIPs. Targeted lessons often occurred after the class conducted an empirical investigation and constructed small group or whole class knowledge products. A third assessment was implemented and then discarded from this study. The third assessment was problematic due to timing within the unit, content understanding and knowledge product. Additional classroom instruction time would have been beneficial for the students.

Table 5

The number and lesson placement of each of the EA taken by the students

School H		
6 Chemistry (16 lessons)	2 assessments	Lessons 6 and 16
7 Biology (12 lessons)	2 assessments	Lessons 5* and 11
School S		
6 Chemistry (16 lessons)	2 assessments	Lessons 6 and 16
7 Biology (12 lessons)	2 assessments	Lessons 5* and 11

Note. Lesson 5 from 7 Biology was discarded because of issues with content.

Semi-structured interviews. Along with the embedded assessments, I collected semi-structured interviews from 14 focus students to understand the rationale for changes to their knowledge products and thoughts about the EIPs targeted on the embedded assessment questions. Students used their knowledge product from their embedded assessments to respond to the interview questions which were similar to the questions provided on the embedded assessments, but further prompted students to justify their written responses for each of the four epistemological considerations. The teachers assisted in selecting specific focus students for the study providing a variety of academic skill levels within the science classroom. I conducted semi-structured interviews within a week after I administered each embedded assessment. Interviews generally lasted 15 to

30 minutes with approximately twenty questions, allowing enough time for students to reflect and justify their assessment responses (Appendix D & E).

I interviewed seven students from each school after taking each embedded assessment. At both School H and School S, I conducted a total of four interviews for each student, with two interviews per unit (Table 6). Similar to what has been previously described, the interview for Lesson 5 of the 7 Biology unit was discarded due to the issues of timing within the unit, content understanding and knowledge product.

Table 6

Number of semi-structured interviews preformed for each unit and number of students interviewed

School H	Number of interviews	Number of Students
6 Chemistry	2 interviews	7 students
7 Biology	2* interviews	7 students
School S		
6 Chemistry	2 interviews	7 students
7 Biology	2* interviews	7 students

Note. The first interview was discarded due to the issues with understanding the content.

Data Analysis

As mentioned earlier, each epistemological consideration includes a range of ideas varying in sophistication. Four coding schemes were developed representing each consideration and the varying levels, moving toward a more sophisticated response. For simplicity and continuity, examples of each of the coding schemes are modeled using the 6th Grade Chemistry unit.

Type of account coding scheme. The epistemological consideration of a type of account includes how and why the phenomena occurs (Table 7). The coding scheme used for this consideration begins with the most basic components or factors (level 1) and works towards more complex reasoning (level 3). It includes the components, sequences, and causal factors that link the cause and effect of the phenomena. When scoring a scientific model, both the drawn model and any provided description associated with the model are coded together to give an overall view of the product. The level one response for attention to type of account focuses on implicit student inclusion of factors associated with the particular unit being coded. These factors include parts of the account that make it function. The overall idea of the factor is missing from the knowledge product and can be seen as a statement with no context. An example of this would be to state "air particles move the odor." This explanation is missing how and why air particles move the odor particles. The level two response makes the factors explicit and the response has reasoning behind it for how and why it is needed. An expansion of the statement that air particles move the odor is done by stating that the "air particles collide with odor particles, causing them to move in another direction." If a student has all of the main factors that are being coded for in their knowledge product, it is then coded as a level 3 response. For the 6th Grade Chemistry Unit, this is seen by explicit inclusion of "collisions between the particles and the random movement or diffusion of particles throughout a room." If a response has multiple factors but they are not explicit, then it is still considered a level 2 response. Each phenomenon from each unit has a complete set of parts and/or factors that are needed for the higher levels to be achieved by the students.

Table 7

Type of account coding scheme (Chemistry)

Score	Levels	Example/Reasoning
3	All factors present and reasoning explained.	Knowledge product contains an explanation for why the factors are needed and how they are used. "All particles are moving in all directions, they change directions when one bumps into another. The particles in the liquid are changing into a gas state by evaporation." (201046 student code)
2	Contains specific verb for what the particles are doing.	Verbs like "move" or "travel" are too general. Verbs like "push", "carry", "collide", or "bounce" are specific.
2	Contains noun or phrase to that describes particles movement around the room	"bouncing causes random movement". "diffusion", "air particles carry/push odor around the room"
1	Factor is explicitly named in the knowledge product	Explicitly names air or air particles as a factor. "The air particles
1	Contains factor that causes odor to move across the room	"air moved the odor"
1	Contains a factor other than air particles, odor particles, or generic molecules that explains the phenomenon	"a fan blew the odor across the room", "magical pixies carry the odor across the room"
0	No response given or is off topic	Off topic. "I don't know."

Once each of the coding schemes were refined, inter-rater reliability was established for each epistemological consideration. When looking at the consideration for type of account, I achieved an inter-rater reliability of 95% between two team members coding 20% of the students' embedded assessments.

Generality coding scheme. The epistemological consideration of generality relates to students' understanding of the relationship between their current knowledge products and other knowledge products and phenomena in science. Students' ideas and actions range from the desire for very specific products that explain particular observed phenomena, to more sophisticated and general products that can apply to a broader range of phenomena (Table 8).

Within the coding scheme, level one responses do not include generality but focus on the original context, and create an accurate answer rather than using scientific principles to find an answer. A level two response consists of understanding the components of the model and using them with an analogous example of the phenomenon. Within the chemistry unit, the level two responses may replace the specific odor of strawberries, and state that the "odor could be something else like oranges or cinnamon." Level three responses consist of replacing the components of the knowledge product with components that fit a broader range or adding additional language to show how the new knowledge product can handle more cases.

Table 8

Generality coding scheme (Chemistry)

Score	Levels	Example/Reasoning
4	Response makes explicit the conditions that the generalized product can or cannot be applied	"My model is unable to work on any kind of gas but will not work for solids or liquids." (hypothetical response)
3+	Identifies and generalizes the entire account with the intent to apply to multiple context	Entire account is generalized with the intent to apply it to other contexts. "The particles from the source can be anything the detector can sense." (hypothetical response)
3	Identifies and generalizes components of the account with intent to apply to other context	Multiple parts of the account are generalized with the intent to apply them to other context. Response does not have to give other examples. "The odor could be any kind of particle that can be detected by the nose." (hypothetical response)
3-	Identifies and generalizes components of the account	One or more parts of the account are generalized with no intent to apply to multiple contexts. "My model does explain how. It also explains this because it shows moving particles." (201064 student code)
2+	Identifies the relationship between the original and the alternate examples without using generalized components	Response states that the examples are interchangeable because they represent the same thing without using the general terms. (It would work because in my model it shows that particles are coming up from the liquid. And that would change the paper color." (201051 student code)
2	Recognizes the representational role that a component plays in the product by replacing it with an analogous component with intent to apply	Response replaces one component with an analogous one. "The smell from the candle could be oranges instead of strawberries."
2-	Defines the representational role that a part plays in the product	"The candle is the source of the smell."
1	Response is made looking for accuracy or contains no generality	Only contains a repetition of the prompt and is very specific to the prompt. "In the bottle of ammonia all the particles are moving." (201046 student code)
0	No response given or is off topic	"I don't know", is off topic, or no response

Within the chemistry unit, a student may explain how odors move across a room and apply the account to work on any gaseous particle movement. The original specific context is mapped to the new generalized knowledge product, its underlying principles, and is made explicit to work for other phenomenon. A level four response makes explicit the situations in which their generalized knowledge product cannot be applied. When looking at the consideration of generality, I achieved an inter-rater reliability of 85% between two team members coding 20% of the students' embedded assessments.

Audience coding scheme. The epistemological consideration of audience contains responses from students regarding how easily others could understand, use, and be persuaded by their knowledge product (Table 9). In a level one response students focus more on the accuracy their knowledge product gives the reader or states that the product is for the teacher or another authoritative figure. For level two responses, the student focuses on making the product clear to understand with no mention of the rebuttal of alternatives or critiques. Level three responses consider both how well the knowledge product will be understood and they explicitly address alternative conceptions and counter-arguments that could be used. A level four response considers potential alternatives or critiques that have not been previously raised that can be rebutted with the current knowledge product. When looking at the consideration of audience, I achieved an inter-rater reliability of 90% between two team members coding 20% of the students' embedded assessments.

Table 9

Audience coding scheme

Score	Level	Example/Reasoning
4	Considers whether potential alternatives or critiques that have not been raised can be rebutted with the knowledge product	"My model is unable to address particles that are not in a gaseous state of matter" (hypothetical chemistry response).
3	Considers how well the knowledge product will be understood and persuade others. Also understands how well the knowledge product will respond to critiques and alternatives given by others.	Explicitly addresses the alternative conception/counter-argument and it is clear that the response is trying to help the confused student. "I can explain this because if it moved in one cloud, then you couldn't smell it in different areas. I would also show the classmate and explain that." (201048 student code)
3-		Explicitly addresses the alternative conception/counter-argument. "My model explains that a smell is made up of particles. The particles stay particles and don't form a cloud." (201064 student code)
2	Communicates knowledge of their knowledge product with no consideration to rebuttal or what others would do.	Clarifies the knowledge product for better understanding with explicit knowledge of a non-authoritative audience. "My model could explain that that's not what happens because I show the ammonia evaporating and moving around and getting to your nose." (201052 student code)
2-		Restates or clarifies their original knowledge product with no explicit audience. "Yes, I have air particles moving everywhere to get to the nose." (201046 student code)
1	No audience present or audience is viewed as teacher/authority, looks more to correct an incorrect account	Response looking more at accuracy or an authoritative figure with no consideration of other audience. "I don't think my model can because it needs more detail." (201057 student code)
0	No response given, off topic, or "I don't know"	Off topic, "I don't know."

Justification coding scheme. The justification coding scheme focuses on students' considerations regarding where ideas come from and how the ideas must be supported and evaluated. I see students exhibiting decisions focusing on accuracy and authoritarian support (i.e., teacher) and others emphasizing criteria of empirical and theoretical supports (Table 10). Level one responses in justification only look for accuracy and do not help support the claim. These can be in the form of random, non-relevant facts, or a statement that the response is correct with nothing to support the claim. Level two responses in justification only contain the source of the supporting information with no explanation of why it is helpful or important. These could be experiments conducted, class discussions, previous knowledge product building, or something from outside of class. Level three responses contain two of the three main parts of justification. These parts include the source described above, the punchline of the experiment or theoretical claim, and the connection of how the justification helps to support the question being asked. A level four response will contain all three of the parts described. An example comes from the 6^{th} Grade Chemistry unit experiment which students perform with a flask filled with ammonia and litmus paper (source). Students might state that they know their claim is correct, based on their observations. They saw that over time the litmus paper changed colors without touching the liquid in the flask (punchline). They would then state that this showed them how the evaporated liquid that touched the litmus paper had to still be ammonia in a gaseous state and it was still able to react with the paper (reasoning for inclusion). When looking at the consideration of justification, I achieved an inter-rater reliability of 80% between two team members coding 20% of the students' embedded assessments.

Table 10

Justification coding scheme

Score	Level	Example and/or Reasoning
4	Contains all three pieces	Contains source, punchline of the experiment, and connection of how it helps answer the question. "One of the most important activities that we did was the syringe activity because it showed that there was air trapped in the syringe. When you pushed on it… It helped me decide on it. What to put in my model because it showed that air can move, be compressed, and expand." (201045 student code)
3	Contains two of the three pieces	Only states two of the following pieces: source, punchline of the experiment, connection of how it helps answer the question. "The most important activity was the liquid ammonia and the indicator paper… When the indicator paper was in the flask it turned colors." (201028 student code)
2	Only contains source	Only says where information originates but does not say what knowledge it provides. "The best project we did as a group is where we drew a model." (201057 student code)
1	Looking for accuracy	Only stating non relevant facts to support claim
0	No justification present	Contains no justification

Results

The findings presented here respond to the research questions supported by the previously described framework. First, I describe the trends observed in the students' progression of the different epistemological considerations. I wanted to observe how the students' views of the EIPs changed over time, both individually and compared to one another. Next, I took two of the interview students, one from each school, and observed the quality of their responses to see how they view each of the epistemological considerations. I wanted to observe how individual students may look at the EIPs in different ways.

Research Focus 1: Epistemologies in Practice over Time and Across Contexts

As previously outlined, the two schools used a provided curriculum, IQWST, and within the units enacted at each school, students created knowledge products (models and explanations). From these knowledge products I determined a representative code/level to show the students' progress over time. This code was determined for each of the epistemological considerations found within the embedded assessments and interview data sources. Starting with School H, it can be seen that each of the epistemological considerations show different trends.

Type of account. In the first chemistry assessment, students started with an average coding score just above level one (Figure 2). Approximately 60% of the students created accounts that only named the factors at hand with no explanations of them (Figure 3). Only 30% of students created accounts that named the factors and explained them either partially (20%) or fully (10%). During the second chemistry assessment, the average response for creating an account rose to just below level 2, with an increase in students responding with level 2 (~30%) or level 3 (~30%) accounts. For this assessment only 35% of students responded with a level one type of account. The 7th Grade Biology assessment showed a slight decrease in the average student score, coming just below the previous assessment when slightly more students (~40%) responded with a level 1 response and slightly fewer students (~25%) responded with level 3 responses. Approximately the same number of students responded with a level 2 response in the last two assessments (~30-35%). Even with the slight decline from the second to the third assessment, School H had an overall increase from the students' use of type of account within their practices work. Looking mainly at the first and final assessments, the number of students recording level 2 and level 3 responses in the final assessment (Biology 1) are much greater than they were in the first assessment (Chemistry 1) with more than half of the students receiving higher scores (Figure 3).

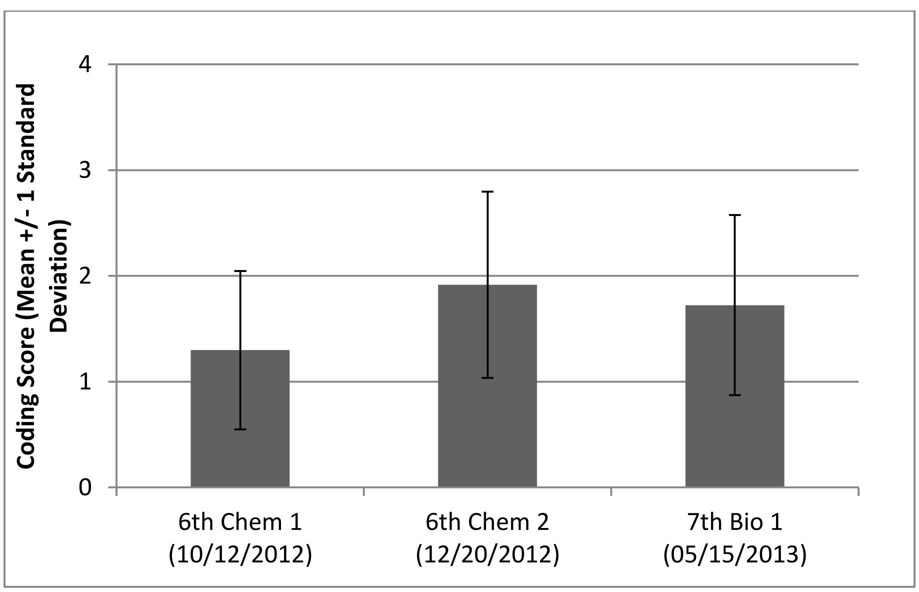

Figure 2. Average type of account coding scores for School H

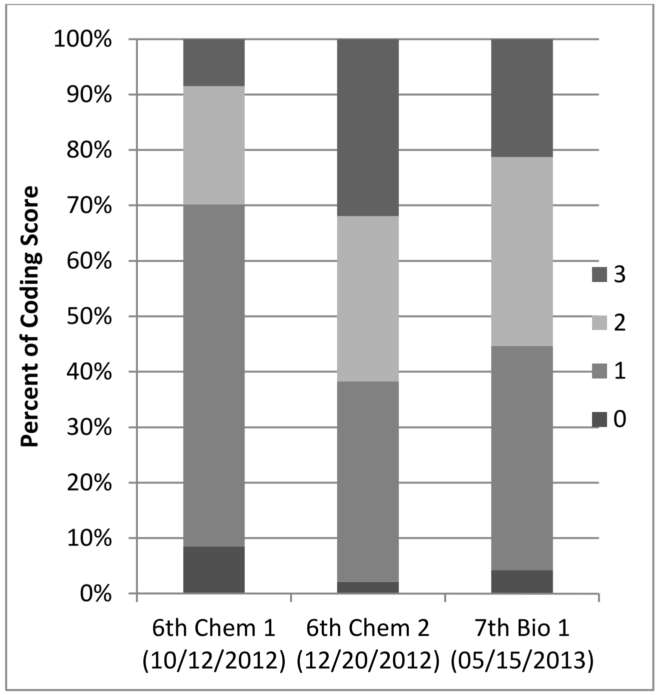

Figure 3. Distribution of type of account coding scores for School H.

At School S, similar trends can be observed when analyzing the epistemological consideration for type of account. Students started out with an average coding score just above level one with almost 70% of students responding with a level one type of account (Figure 5), and with only approximately 25% of students able to create a level 2 (~15%) or level 3 (~10%) response. Next I found that only 60% of the students gave a level 1 response for the second chemistry unit. An increase in level 2 responses from more students (~30%), and between 5 and 10% of students giving a level 3 response allowed for a slight increase in the overall average from the first assessment (Figure 4). The final assessment showed a little more overall increase in average score with a little over 30% of students providing a level 2 mechanistic response and about 20% providing level 3 responses. The remaining students (~45%) still provided a level 1 response for the type of account. This shows an overall increasing trend in students' type of account. Similar to School H, School S showed a large improvement when looking at the first and final assessments. The proportion of students recording level 2 and level 3 responses in the first assessment (Chemistry 1) are much lower than they are in the final assessment (Biology 1) with almost 75% of students receiving low scores (Figure 5).

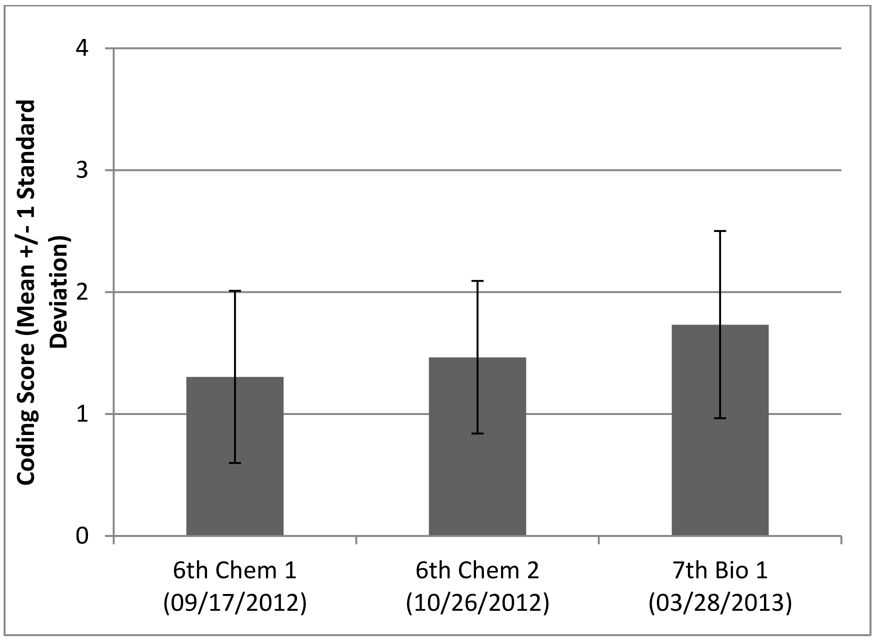

Figure 4. Average type of account scores for School S

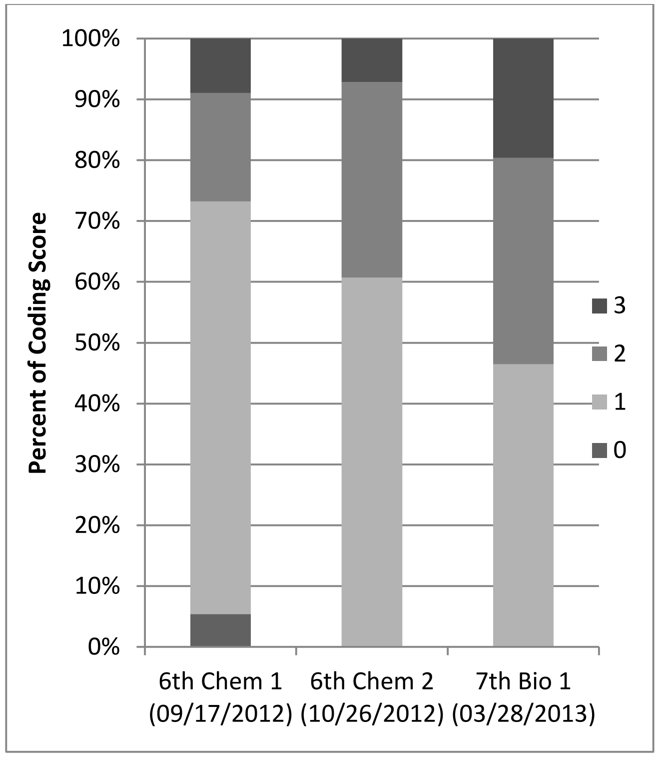

Figure 5. Distribution of type of account scores for School S

Generality. At School H, in the first chemistry assessment, students began with a score in generality just below level 2 (Figure 6). Approximately 35% of students responded with a level 2 response, meaning they only gave an analogous replacement for one of the components (Figure 7). About 20% took a further step by providing the reasoning or connection between the original and alternative, and about 10% of students were able to fully generalize that component. The remaining 35% of students either could only give the components use, or were only looking for accuracy or specificity of the knowledge product. However, I saw a decline when moving to the next assessment, where far more students (~55%) responded by only looking for accuracy or specificity in their knowledge product. This resulted in the average score of generality to be halfway between a level 1 and level 2 response. Approximately 25% of students gave a response that recognized the components role and then may have replaced it with an analogous component. Only between 10% and 15% of the students were able to fully generalize one or more parts of the account. These numbers combined show significant generalization with many more students looking for accuracy or specificity of the type of account. The final assessment shows even more students with this mind set, when almost 60% of students looked for accuracy or specificity. Just under 10% of students only stated the role of a component, about 15% were able to replace it with an analogous component, and just over 5% of students were able to state how the original and alternative components were related. No students gave responses in this assessment that contained one or more of the components being fully generalized. With many more level 1 responses and few level 2 responses, the average score was just over level 1. Students shifted toward specificity rather than generality. This caused the overall trend for generality to be a negative progression. When looking at the first and last assessments, the number of students responding with level 1 responses increases by almost 3 times (Figure 7). Looking at the same two assessments, the number of higher level (levels 2-3) decrease by at least half during the period of time, with only ~30% of students receiving higher level scores.

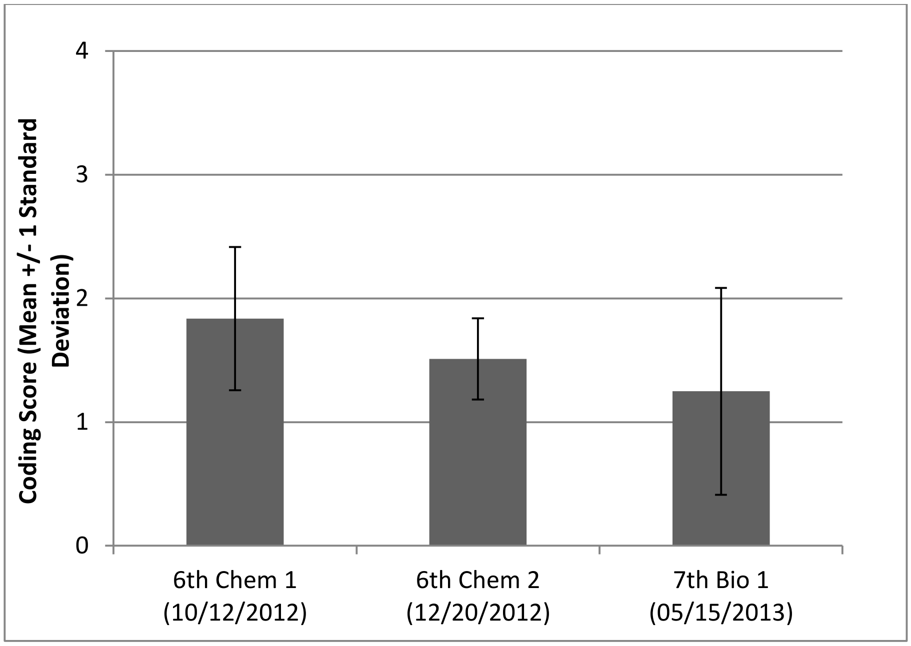

Figure 6. Average generality scores for School H

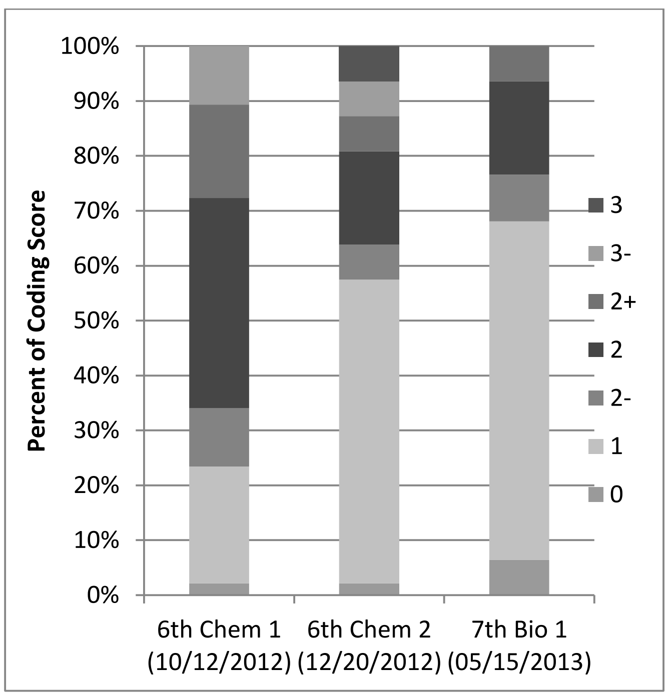

Figure 7. Distribution of generality scores for School H

At School S, students also started with an average score just below a level 2 response (Figure 8). Just under 25% of the students gave a level 1 response and about 35% of the students gave a level 2- response (Figure 9). About 25% of students created a response that contained the representational role of the component, replacing it with an analogous component (level 2+). Only 5% of the total did not recognize the correlation or connection between the original and alternate components (level 2). The remaining 10% of students provided one or more generalized parts of the account. In the second assessment the students' average score was below the first assessments score, halfway between a level 1 and a level 2. Many more students (~55%) responded with level 1 responses. There were very few scores in the level 2 range (~25%) and even fewer in the level 3 range (~20%) resulting in an overall negative trend. The average score in the final assessment dropped even more, down to just above a level 1 average score. In the final assessment more students created level 2- (~20%) and level 2+ (~10%) generality responses compared to the previous assessment, but there were still many students who created level 1 (~50%) responses and several students (10%) responses contained no generality at all, warranting a score of level 0. Overall, the generality score for School S shows a negative trend in average score. When only looking at the assessments, the number of students responding with level 1 responses more than doubles from the first to the last assessment (Figure 9). Looking at only the first and last assessments, the number of higher level (levels 2-3) decrease by at least half during the period of time, with only ~40% of students receiving higher level scores in the final assessment.

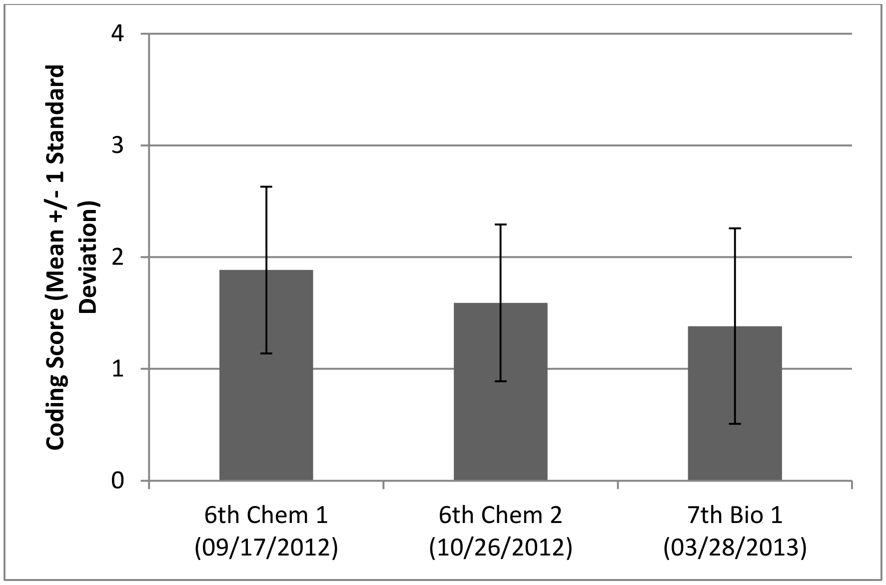

Figure 8. Average generality scores for School S

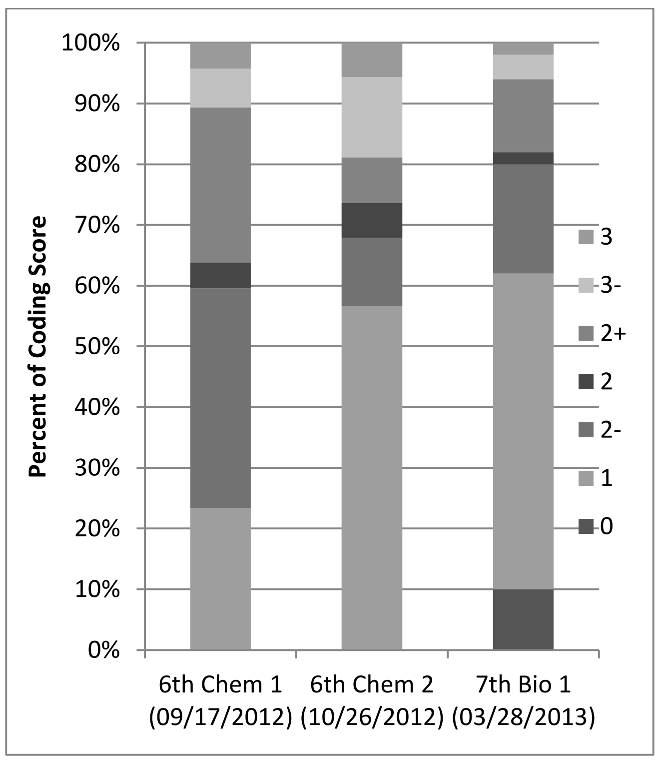

Figure 9. Distribution of generality scores for School S

Audience. The first chemistry assessment average score for audience at School H was just below a level 2 (Figure 10). Approximately 35% of students clarified their knowledge product, warranting a score of level 2- (Figure 11). Another 30% of students also could clarify their knowledge product, but explicitly said who their product was useful for, warranting a score of level 2. Only about 10% of students were unable to make their knowledge product clearer or they believed it to be only for the teacher or another authoritative figure. These students scored a level 0 (under 5%) or a level 1 (~10%). The remaining students (~20%) made their product clear and helped another student understand or use their knowledge product against a rebuttal or critique. For the second assessment, the average score was halfway between a level 1 and level 2 response. In this assessment many more students responded with a score of 2- (60%). Far fewer students gave a level 2 (~15%) response or a response in the level 3 range (~5%). This caused a decrease in the overall average score. For the final assessment, about the same number of students (~65%) still gave responses with a score of level 2-. Even more students responded (~20%) with a score of level 1 and only 10% of students could identify the audience as other students or non-authoritative people. With this decrease in average scores, the overall trend of the consideration audience for School H was negative. When looking at only the first assessment and the final assessment, over half of the students gave more sophisticated responses (level 2-3) in the Chemistry 1 assessment (Figure 11). In the Biology 1 assessment, only 10% of students were able to give a more sophisticated response, while the other 90% gave a low level (level 1 or 2-) response.

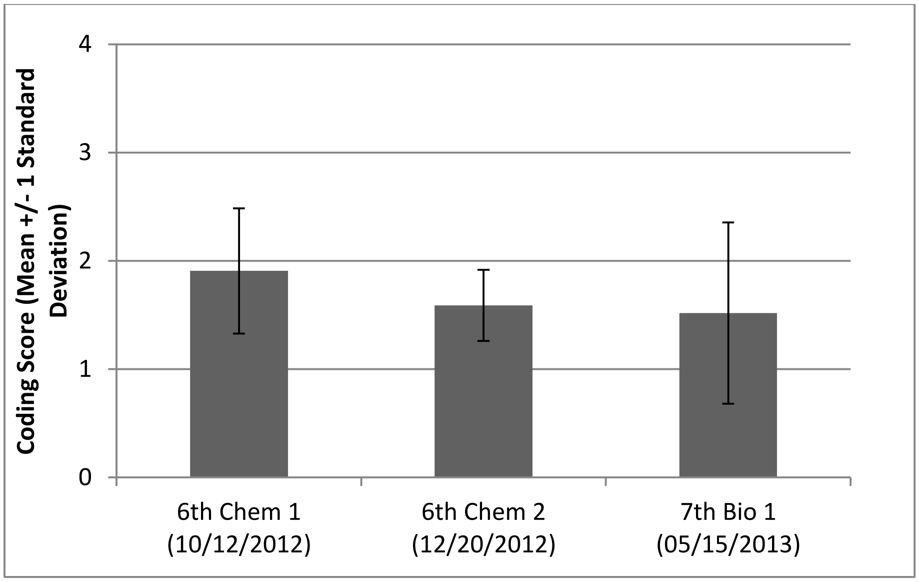

Figure 10. Average audience scores for School H.

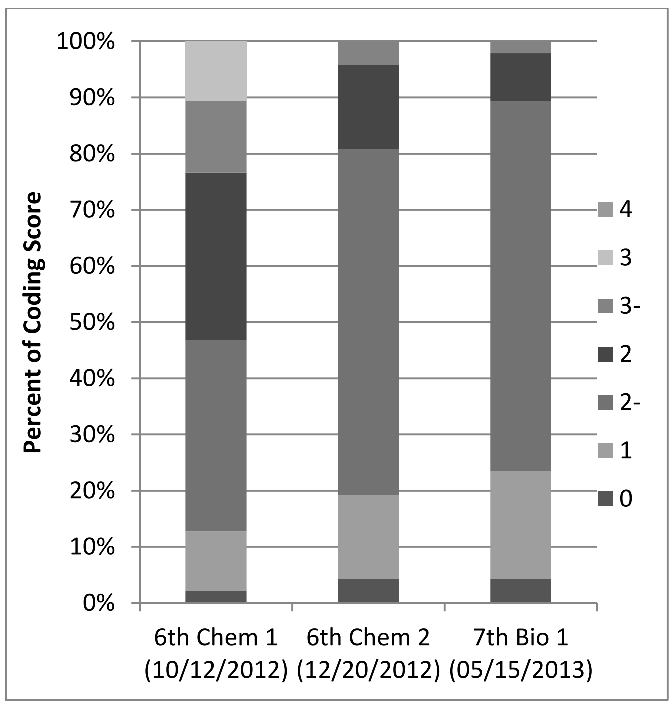

Figure 11. Distribution of audience scores for School H.

The first assessment at School S had a score of level 2 for the epistemological consideration of audience (Figure 12). I found 65% of students clarified their knowledge product, but did not explicitly state their audience (Figure 13). Also, only about 10% of students clarified their audience (level 2), and about 20% of students addressed the rebuttal or critique (level 3-) and helped the confused student at hand (level 3). The second assessment had an average score of just under level 2. Many of the students (~80%) clarified their knowledge product but did not explicitly state their audience (level 2-). Very few students (>10%) were able to clarify, state the audience (level 2), address the rebuttal or critique (level 3-), and help confused students (level 3). About 15% of the students identified the audience and the teacher or other authoritative figure (level 1). In the final assessment 10% of students did not address any audience (level 0) and about 35% of the students addressed their audience as the teacher or other authoritative figure (level 1). About 45% of students clarified their response but did not identify their audience (level 2-). Only about 5% of students were able to clarify and address the rebuttal or critique (level 3-). Because of the increases in no audience or an authoritative audience, the average score for the final assessment was about halfway between a level 1 and 2 response. The overall trend for audience at School S was a negative. During the Chemistry 1 assessment almost 35% of the students gave more sophisticated responses (level 2-3) (Figure 11). In the Biology 1 assessment, 95% of students gave a low level (level 1 or 2-) response and only 5% of students only gave a more sophisticated response of level 3-. None of the students gave a response of a level 3.

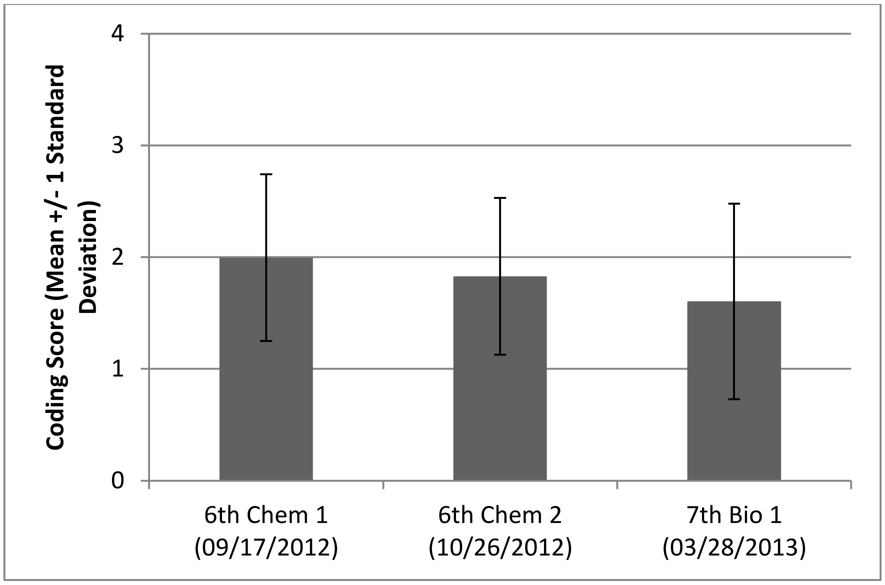

Figure 12. Average audience scores for School S.

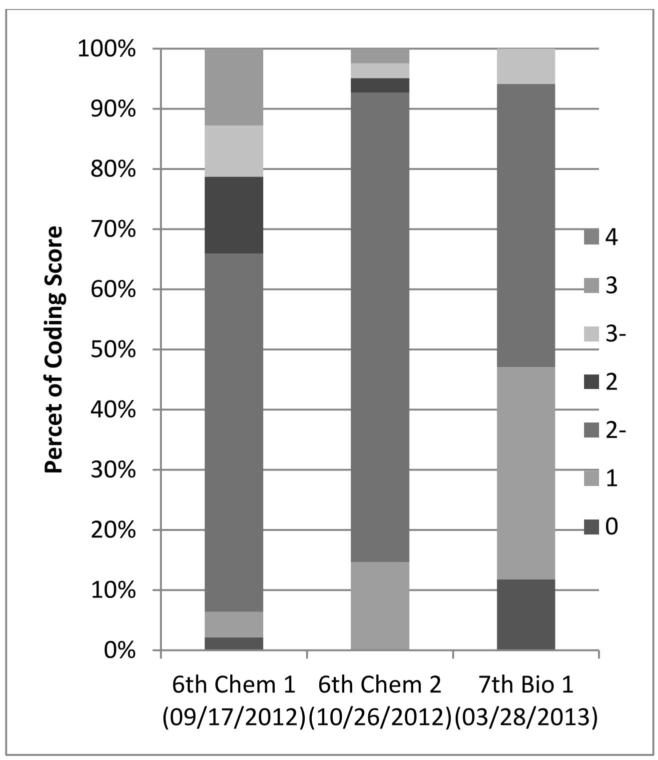

Figure 13. Distribution of audience scores for School S.

Justification. At School H, in the first assessment, justification started above level 2, just below halfway to a level 3 response (Figure 14). Many of the students (60%) responded with only the source for justification, resulting in a score of level 2 (Figure 15). Slightly more than 30% of the students were able to give the source and also state either the theoretical claim of the source or the reasoning it was important to include in the knowledge product. This resulted in a score of level 3. Less than 10% of students only looked for accuracy in their knowledge product. During the second assessment almost all (~95%) of the students responded by only looking for accuracy and not giving the source of the data. This resulted in the average score of the second assessment being a level 1. Very few (>5%) students gave a source for their data and they either gave the theoretical claim or the reasoning for its inclusion (level 3). The final assessment for School H had an average score just below level 2. Approximately 55% of the students did not provide the source of their data resulting in a score of level 1. About 20% of the students only gave the source of their data (level 2) and the remaining students (~25%) were able to give the source and either the theoretical claim or the reason they included it in their knowledge product (level 3). Because of the second assessments drop to level 1, the overall trend for justification for School H was a large decrease followed by modest increase. The students did not fully recover to the original starting average at the end of the second unit. In the first assessment, 95% of students gave the source with 35% including either the theoretical claim or the reasoning for inclusion (Figure 15). In the final assessment, this lowered to 45% of students who gave the source and almost 25% of students gave either theoretical claim or the reasoning for inclusion as well.

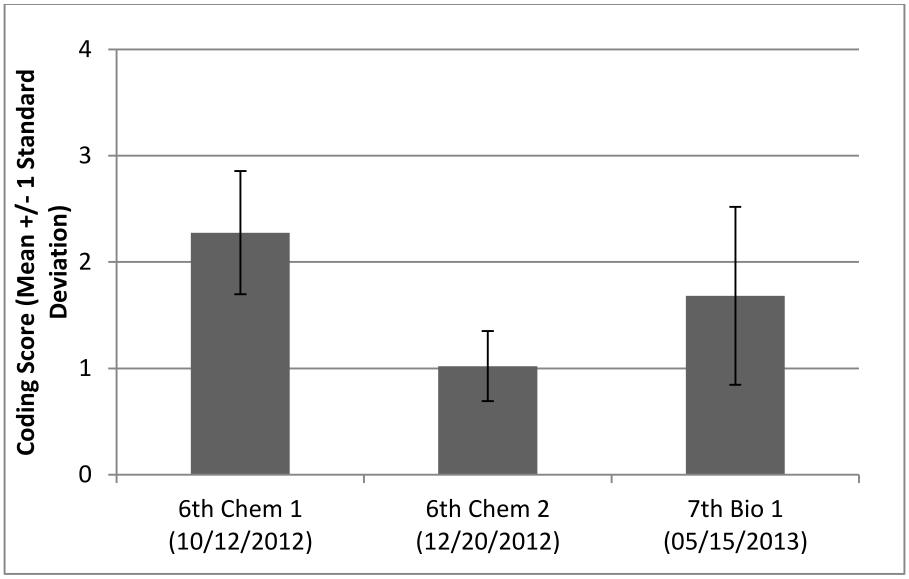

Figure 14. Average justification scores for School H

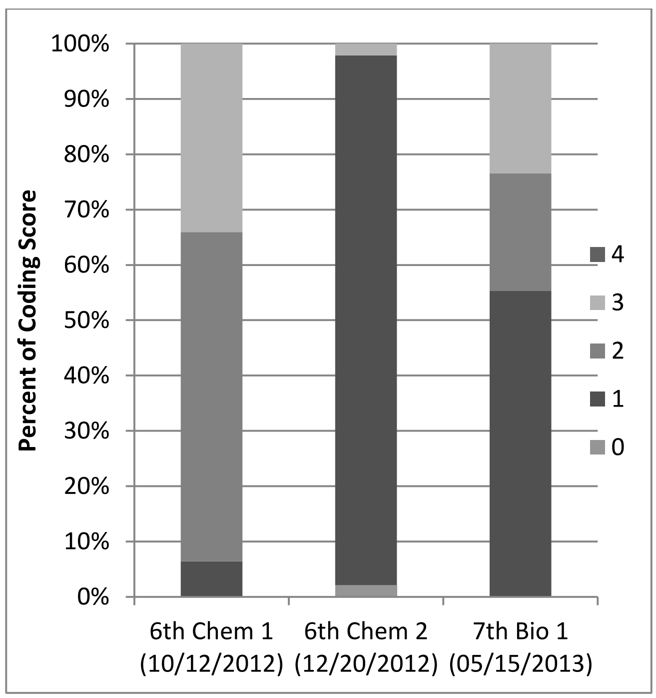

Figure 15. Distribution of justification scores for School H.

School S began the first assessment at an average of about half way between a level 2 and a level 3 for the epistemological consideration of justification (Figure 16). About half of the students provided only the source of their data resulting in a level 2 response (Figure 17). Many of the students (~35%) provided the source and the theoretical claim or the reason they included it in their knowledge product (level 3). Approximately 5% of the students provided all three parts: the source, theoretical claim, and the reason for its inclusion (level 4). Less than 10% of the students looked for accuracy or were unable to include any justification in their knowledge products. In the second assessment just over half of the students (~55%) did not provide the source of their justification (level 1). Approximately 30% of the students only provided the source of their justification (level 2) and the remainder of the students (~15%) provided the source and either the theoretical claim or the reasoning for inclusion (level 3). For the final assessment just over 20% of the students did not give the source of their justification (level 1). Approximately 25% of the students only gave the source of their justification (level 2), while approximately 45% gave the source and either the theoretical claim or the reasoning for inclusion (level 3). The remainder of students (~5%) gave all three parts for a level 4 response; the source, theoretical claim, and the reason for its inclusion. These percentages caused the average for the final assessment to be above level 2 at around the same average score as the first assessment. The overall trend for the students of School S was a dramatic drop below a level two response, but they were able to recover to nearly the same average in the final assessment. In the first assessment, over 90% of students gave the source with 40% including either the theoretical claim or the reasoning for inclusion (Figure 17). In the final assessment, this lowered slightly to almost 80% of students who gave the source and just over 50% of students gave either theoretical claim or the reasoning for inclusion.

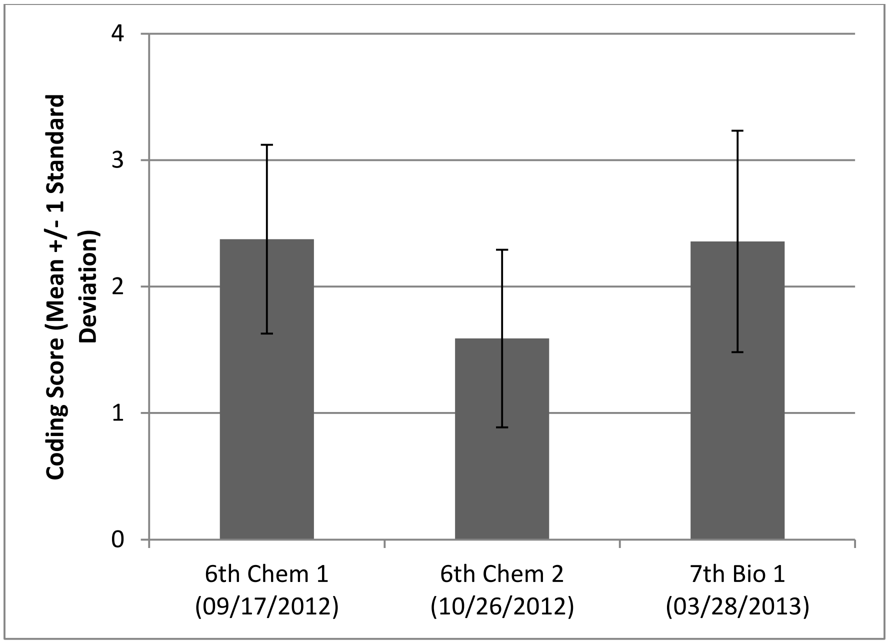

Figure 16. Average justification scores for School S.

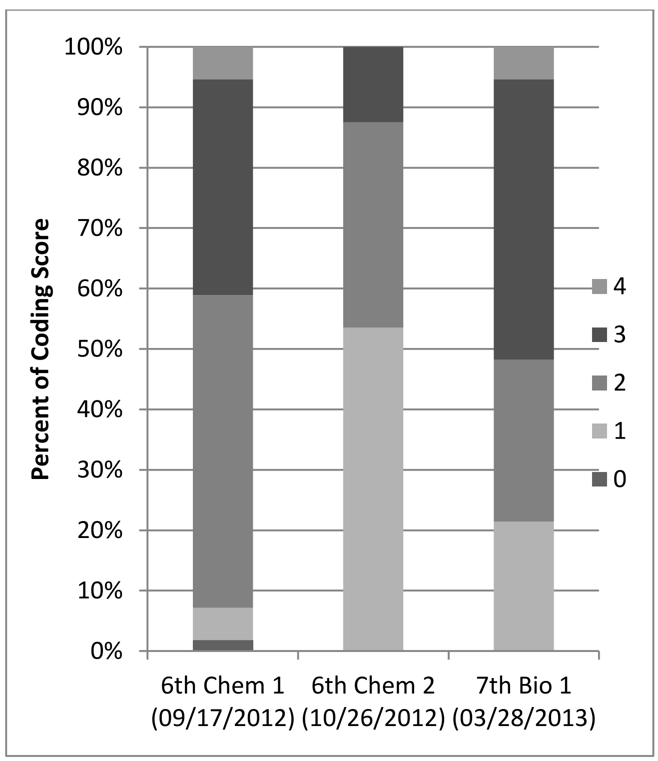

Figure 17. Distribution of justification scores for School S.

Comparative view of the epistemologies in practice. Both School H and School S showed similar coding scheme average scores and trends for multiple assessments (Figure 18). The only major differences between the two schools occur in 6th Chem 2 for the considerations of type of account and justification and in 7th Bio 1 for the consideration of justification. For 6th Chem 2 consideration for type of account School H had a coding scheme average score ~0.5 higher than the average score for School S. In the same assessment for the consideration for justification School S had an average coding score ~0.5 higher than the average score for School H. During the 7th Bio 1 consideration for justification School S had an average coding score ~0.6 higher than the average coding score at School H.

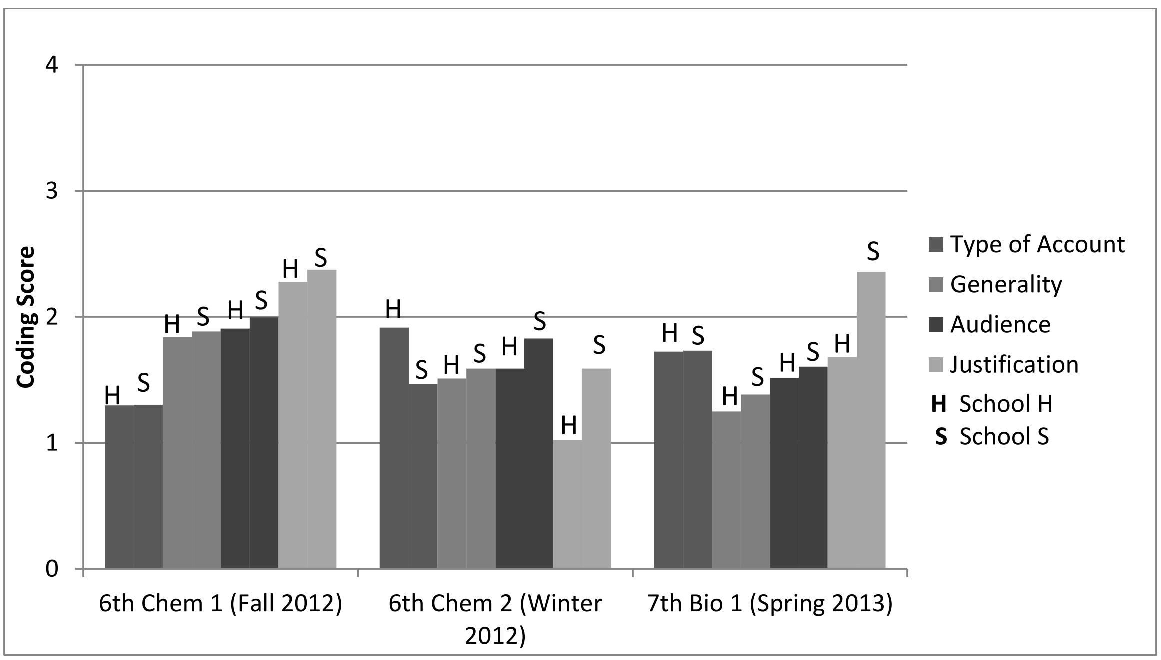

Figure 18. Average scores for the EIPs from School H and School S over time

Individual

Fourteen students, seven from each school, were chosen by the teachers as representatives of the whole class. These students varied in ability when it came to the science classroom. The purpose of these interviews was to determine what was important to the students when dealing with their knowledge products. Each of the fourteen students are unique and have different abilities when looking at their interviews; I present data from two students, one from each school, based on their performance in both the classroom and their embedded assessments. These two were chosen to represent the differences seen, where each of the students focused on different epistemological considerations.

Zoe. Starting with School H, Zoe was very active in the classroom and participated during most of the activities and discussions during the study. Her embedded assessments were very similar to that of the majority of students. Her scores for all four epistemological considerations are very close to the averages of the whole group. When it came to her interviews, she showed some similar trends to the group but her scores were often higher than the averages embedded assessment coding scores of the student body.

Type of account. During the first interview, she was asked to answer the question of how and why an odor moved across a room. She gave the complete sequence and named the factors that contributed to the phenomenon (a level 3 response). Her verbal response contained all of the parts needed whereas her knowledge product did not (Table 11). She started by describing all of the different parts her model showed and then stated that, "…basically [the odor] evaporates… and they are just moving around in the open space until they bump into each other and the nose will suck them up so they move to the nose." The second interview asked the same question of how and why an odor moved across a room. Zoe scored a level 3 here as well because she maintained the ability to give the complete sequence and factors needed to thoroughly explain the phenomenon. For the final assessment, she was asked to explain how and why everything worked together inside her body. Her response lacked the connection that links the parts of her explanation. She provided the main idea by saying that "everything works together in a system and it works together to keep me alive." She did not, however, provide the how or why everything works together.

Table 11

Zoe's embedded assessment score and interview score and response for the consideration for type of account

	EA Score	Interview Score	Interview Response
6th Chem 1	1	3	"…basically [the odor] evaporates… and they are just moving around in the open space until they bump into each other and the nose will suck them up so they move to the nose."
6th Chem 2	3	3	"All the other gasses in the air are going to touch the top layer of the liquid and it's going to evaporate and go into the air and then they are going to go into a straight path until they hit another object or another particle until they reach your nose."
7th Bio 1	2	2	"…everything works together in a system and it works together to keep me alive."

Generality. Zoe's ideas about the epistemological consideration of generality during the interviews showed a different trend from the overall group. During the chemistry unit, she was asked if her model should explain how particles like odors and air move around or if it should be specific and describe how something specific like popcorn or perfume particles move around the room. For both interviews she provided responses stating how her model would work for any kind of smell. She talks about how you are not limited to one kind of smell but does not move past odors being the only thing her models could show. During the biology unit she was asked if her explanation should explain how any system works together or specifically how her body's systems work together. She moves past the limitation of specificity by stating her explanation can be used on any kind of system, "not just systems in the body". She further emphasized the importance of its generality by stating:

> …that a system is something that is made up of a bunch of different parts that are connected to perform a certain function. Like a pen, its function is to write. And I also said that if you take out a part it would not work, like the pen would not be able to write if you took out the ink. Or like any other kind of systems. (7th Bio 1 Interview)

This description is considered a level three response because it generalized the entire explanation. This showed that she cared about the explanation being able to work on more than just explaining how the body works.

Table 12

Zoe's embedded assessment score and interview score and response for the consideration of generality

	EA Score	Interview Score	Interview Response
6th Chem 1	3-	2+	"[Would have to] change some of the steps because you don't smell garbage by spraying anything. I think you just change some of the steps and the perfume bottle to garbage."
6th Chem 2	2	2+	"I would have to change the process of how it turns into a gas because not all of the [sources] melt like a candle does."
7th Bio 1	2	3	"…if you take out a part it would not work, like the pen would not be able to write if you took out the ink. Or like any other kind of systems."

Audience. For the 6th Chemistry unit she was asked how she would convince another student how and why particles did not move in a straight line from the source to the nose. She started by giving a counter-argument on why the other idea would be wrong and provided examples from her own knowledge product to further emphasize this fact. When looking at who else would be able to use her knowledge product or how she would convince someone else, Zoe's consideration about the audience lessened over the interviews. As time progressed, her responses decreased by saying it could be used by someone who wants to know more about it and stating they could just look at hers. She did not state how her knowledge product would help someone else. The 7th Bio 1 question asked her to explain who she believed her explanation was for and why. In this final assessment, she only states that they could just look at her product, but does not say how it is helpful for anyone.

Justification. In all of the assessments, for the epistemological consideration of justification, the questions ask what the most important pieces of evidence that were performed in class and how were they helpful. Here Zoe showed similar but stronger trends, her scores were higher than the averages of the whole group but followed the same trend. In the first assessment, she provided a level 3 response by stating where her ideas originated and why they were included in the product. She does not however say why they were important. In the second assessment, she provided multiple sources for her justification, but did not provide the how or why they were needed. Her sources included both experiments and discussions from the classroom and also experiences from home. She increased her score back up to a level 3 in the final assessment by giving the source of her justification and stating why they were included, but still did not provide the reason for why they were important. During this assessment, she also gave several examples for her justification and described why they were included in the explanation.

Kaylee. The student from School S, Kaylee was very soft spoken in class and would normally not participate in group or class discussions during the study. Her assessments and interviews showed very similar trends for three of the four epistemological considerations. The considerations of type of account, audience, and justification were all similar to the whole group's averages. The consideration of generality, however, showed a different trend.

Type of account. For the first interview, she was asked to answer the question of how and why an odor moved across a room. Kaylee's response for the consideration of type of account provided the factors of particle movement and described how they were moving but she did not give a clear explanation for what was occurring. During the second assessments interview, when asked the same question, she improved upon her previous model by including the factors of particle movement and also stated that "all particles are moving around" and showed them colliding with one another, bouncing in all directions (level 3). This showed an improved grasp on the content and how she paid more attention to the details of the explanation describing what was occurring. In the final interview she was asked to explain how and why everything works inside her body. Kaylee's final interview resulted in a decrease to a level 2. This occurred because she stated how the different parts of the body are all needed and stated how they did experiments about different parts of the body, but she failed to state how the different parts were connected. These showed a varying level of views when she considered the type of account.

Generality. During the chemistry unit, she was asked if she could use her model to explain in general how particles like odors and air particles move around or if it was specific and describe how something like popcorn or perfume particles move around the room. When dealing with the consideration of generality, Kaylee showed a greater attention for the consideration as time passed, where others spent less time on it. Kaylee started out around the same level as the majority of students but as time passed she improved upon her knowledge products ability to work with other situations and phenomenon. In the first interview, her response was focused on the source and how "it could be anything." She knew that the odor could be anything and it would still act the same (level 3-). She improved upon this in the second assessment by stating that her model "could be used for a lot of different things." She said it could be for any kind of odor or anything showing evaporation and that the detector could be anything that detects (level 3). This showed how her model went from any odor to anything in a gaseous state. For the 7th Bio assessment she was asked if her explanation could be used to explain other systems or if it only worked for how the body's systems worked together. She improved her score again by expanding her knowledge product to include other phenomenon that are not directly related (level 3+). When discussing how she could use her explanation on how the body works together she stated:

> I think it could be for anything, it doesn't have to be a living thing, like you could have the basic outline for how a computer works or something and it would be the same outline as what you were talking about. [And] there are different parts to a computer and you would need all of those parts to have the computer work how it is supposed to work and if you took out one part…, a major part in the computer, it wouldn't work. (7th Bio 1 Interview)

She stated that this would be similar to taking out a part in the body, it won't work if something is missing. She finished by stating that this idea will work anything that has multiple parts, and that it could be something simple or something complex.

Table 13

Kaylee's embedded assessment score and interview score and response for the consideration of generality

	EA Score	**Interview Score**	**Interview Response**
6th Chem 1	2	3-	"it could be anything."
6th Chem 2	2-	3	"could be used for a lot of different things."
7th Bio 1	1	3+	"I think it could be for anything, it doesn't have to be a living thing, like you could have the basic outline for how a computer works or something and it would be the same outline as what you were talking about"

Audience. For this consideration, unlike generality, her views followed the same trends as the whole group. The 6th Chemistry assessments asked her if she could use her model to convince another student that particles don't move in a straight line across a room. For the first assessment she provided the idea that another student could do some experiments and use some of the same ideas she did when creating her model. She did not provide any examples of experiments or any idea of how they would help another person to understand the phenomenon. The second assessment showed a similar response and only stated they could just use her model to understand particle movement. The final assessment asked who she believed her explanation was for and why. She showed the same thing that many other students did, where she believed they only need to look at her knowledge product and read it to understand. These responses showed how she did not have a strong view on how to help others understand the phenomenon. She was only focused on that it could be used by others and they could just look at hers to understand the phenomenon.

Justification. For all of the assessments, the questions dealing with the epistemological consideration of justification, she was asked what the most important pieces of evidence that were performed in class and how were they helpful. Kaylee's views on the importance of this consideration were variable. She started off with a great focus on this consideration and provided complete justification (level 4). She did this by stating the source, reason for its inclusion, and what it helped to show for her knowledge product. Kaylee stated that the experiment they did in class with a flask of ammonia with a piece of litmus paper above it helped because it showed her that "…the particles are actually moving." She continued to state it showed how things were moving and she used it in her model because she then knew she needed to show all particles moving in the model. The second interview showed a decrease in focus on this consideration. Here she stated that the class discussions on air helped her and how she could use experiments to confirm or deny ideas but she did not state how the discussions or experiments supported her model. During the final assessment, Kaylee stayed in the same mindset and gave a few examples of experiments preformed in class, but still did not give the reason for their importance or what they showed. These responses showed a trend of a depreciation of focus in this epistemological consideration.

Conclusions

With the findings presented in the previous section, I now turn to the examination of what those findings represent, according to my research question. In doing so, I characterize the trends of student progression in the epistemological considerations and show what individual students believe are important and how their understandings or ideas of the epistemological considerations are retained over time.

Progression of Epistemologies in Practice

Students' focus on each of the epistemological considerations varied from the beginning to the end of the study. Each of the considerations shows a different trend, with similarities between the two schools. In the following pages, I will discuss what each of the trends represent and how they may be related to one another. I will then discuss the factors at hand, which guided some of these trends.

Type of account. Based on the analysis of data, I found that students can make progress constructing more mechanistic explanations of phenomena over time and across subject matter contexts. This was visible when I saw the students move from the first chemistry assessment to the second assessment, but was even more profound when they moved from the second chemistry assessment to the biology assessment. One could argue that because the students are expected to gain content knowledge between the first and second chemistry assessments, they would increase their scores. However, the interesting point here is that when they moved to the new context (biology), they did not return to the earlier performance levels seen in Chemistry 1, but rather they stayed at a higher score. This showed us that the students were using the epistemological consideration of type of account to guide them in the practices within a new context/content. This suggests that students can progress to different more sophisticated levels for this type of account given the appropriate instructional supports. In addition, when I looked at the frequencies of scores, I saw more students with higher frequencies of level 3 in Biology 1 versus Chemistry 1 (Figure 3 & Figure 5). There are also far fewer students earning level 1 scores between the two assessments. The main attribution between the Chemistry 2 assessment and the Biology 1 assessment are more students receiving level 2 scores, instead of dropping back down to a level 1. These help to strengthen the argument that students are using these learned epistemological considerations required to create more sophisticated responses.

I believe that some of these ideas or some of the understanding for the account came from the classroom norms. During this project-based curriculum which foregrounds the scientific practices previously described, teachers were changing their traditional ways of teaching to include more opportunities for their students to explain how and why phenomenon occur. This concept is difficult for both teachers and students to understand right away. Most traditional work focuses on rote memorization and learning science as only a body of knowledge (Ausubel, 2000; Novak, 1994). The methods of asking students to explain ideas of how and why phenomenon occur take time and practice, from both the teacher and the students. From the interactions with the students and collection of their knowledge products during the assessments, I observed that the students' engagement in the practices became more meaningful as they argued about a claim and/or built a consensus model. This engagement may be the reason for the change over time I observed. Instead of learning these epistemological considerations by rote, explicit instruction, they used an implicit and meaningful way to engage in the practices.

Generality and audience. For the epistemological considerations of generality and audience, both schools' coding scores decreased over time during the enactment year. This decrease meant more students focused less on understanding who their knowledge product was for and making their product more specific to the content area at hand. During the assessments students became more involved with giving the "right answer" when creating the knowledge product. This strong focus and understanding of what is needed in the account caused them to be less focused on making it work for other epistemological considerations.

I believe one possible explanation for this is that as students became more focused on another consideration, in this case the consideration of type of account, they became less focused on making their knowledge product work for multiple phenomena (generality) and less time making sure others could use their product to understand the phenomenon (audience). Within the enacted curriculum units, these two considerations were not strongly supported and required more professional development for the teachers to learn these ideas and how to teach them in a meaningful way to their students. There were instances when the teacher did attend to the epistemological considerations in the classroom, but they were not as frequent or useful as type of account. More social student interaction with one another is required for implementing both of these considerations for them to be useful. One example of this is for students to build a group consensus model. This would allow students more opportunities for argumentation and would push the importance of audience.

The teachers did push the idea of an audience during some of the class discussions, where they would have the students present their knowledge products to the rest of the class for critique. Ideally, students would have to convince others in the class that their product was accurate and they would form rebuttals against other students' critiques. Another challenge faced by the consideration of audience is that when the assessments were given to the students, the wording of the assessment questions for this consideration were not seen as clear by the students. This resulted in the students responding with quick, simple answers with little focus on the audience. Students were not challenged in the later assessments to argue their ideas to an audience. I believe this to be a major factor in the students' responses. This supports my earlier statement about if a student does not attend to the epistemological considerations they will not implement the ideas in a meaningful way.

Justification. The epistemological consideration of justification showed a different trend than the other three considerations. The other three showed either a steady increase or decrease in the average coding score, but this consideration differed because it started off by decreasing between the first and second assessment and then increased in the final assessment. The main reason I believe this occurred is because the students went from a scientific modeling unit to a scientific explanation unit. One of the main pieces of a scientific explanation, as described in the beginning of this paper, is how justification is a very important part of the knowledge product (McNeill, 2011, NRC, 2012). Without the justification, the product can be viewed as incomplete. Therefore, the teachers pushed this consideration much more in the final unit than they did in the first unit. Teachers did push it in the first unit, but it was not as often as later. It is also much more difficult for the students to include their justification in a scientific model because focus is on the account. This does not mean the students did not understand the importance of justification when creating a product, only that it is not explicitly included within the knowledge product itself.

Individual student focus and understanding of the considerations. When looking at the two students presented in the results, Zoe and Kaylee, it can be seen how each of the students focus differed and their understanding of the considerations were in different places. Zoe was seen to focus more on type of account and generality, whereas Kaylee focused more on generality throughout the study and focused on justification early in the study.

Zoe. When looking specifically at Zoe and her interview responses showed a greater focus on the type of account. Her understanding of this consideration was shown to be higher during the interviews than when only looking at her assessment. She was much more explicit about what was occurring and including all the parts in her first interview. Zoe also was seen to have a greater understanding of the consideration of generality. This was seen by increasing her understanding and focus on this consideration whereas the rest of the students had a decrease in understanding and focus.

Kaylee. Kaylee had a strong focus and understanding for the consideration of generality and a strong understanding of justification early on. For the consideration of generality, she focused on making her product first work for some things within the same context and eventually for anything that could be seen as related. During this time, she increased her understanding of the consideration and knowledge of its importance within the interviews. During the first assessment she was also seen to have an early understanding of what was required to justify her knowledge product. As time progressed, her understanding or her beliefs of its importance decreased.

These differences between the students' interviews and their assessments were also seen in the classroom.

Summary and Implications

I observed students' knowledge products advance from simplistic to more complex over the study by using epistemological considerations to guide them in a meaningful way. I did see evidence of instructional challenges, which may have limited the use of the epistemological considerations. Most traditional curriculum materials focus on science as a body of knowledge without any attempt to engage students in scientific practices (Ausubel, 2000; Novak, 1994). Here, these teachers were using project-based curriculum that foregrounded the practices of modeling and explanation, but were still challenged to support epistemological consideration to be useful in the construction of the knowledge products. That said, I know that this is difficult for both teachers and students. More support for teacher professional development is needed to move students toward engagement in the scientific endeavor that requires students to construct, evaluate, and revise scientific knowledge. I also saw progress over time, specifically with attending to mechanistic accounts, suggesting promise in using these epistemological considerations as supportive tools for students when making sense of the practice and engaging in meaningful science learning.

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Appendix A

Embedded Assessment for 6th Grade Chemistry, Activity 6.2

Examining Your Model of How Odors Move Across the Room
6th Grade Chemistry, Activity 6.2

Draw your consensus model that shows how odor moves across the room.

1. What is the purpose of your model? What might you use your model for?

2. How does your model accomplish this goal?

3. What makes a good model?

4. Use your model to explain how and why odors move across the room.

5. Use the table below to record the 3 most important changes that you made to your earlier model in order to create the revised model on the first page. For each important change, describe how it helps the model explain the thing you are trying to figure out.
Detailed Description of Change

How does this change improve your model?

6. Do you think your model should explain all the different ways that substances move around like odors or air molecules or should it mainly focus on a specific situation like how popcorn odors move in a room?

Why?

7. Does your revised model use the information from your class experiments, ideas from your classmates and teacher, simulations, or demonstrations that you learned about in class?

If yes, how does it use this information? If no, why doesn't it use this information?

8. Is it important for your model to include the information you learned in class like your class experiments, ideas from your classmates and teacher, simulations or demonstrations?

Why or why not?

9. Who do you think your model is for?

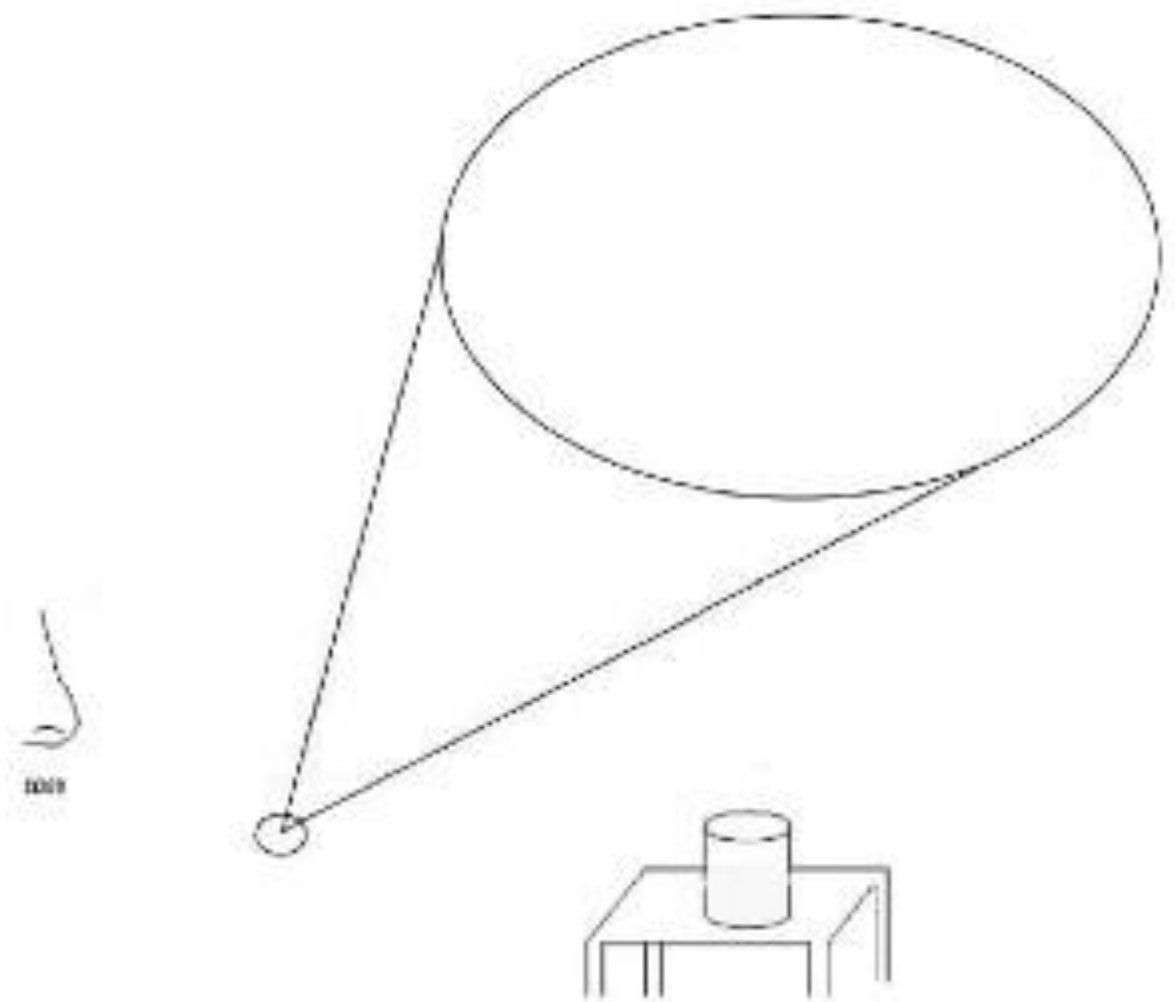
Someone else thinks that odor moves in a straight line from the source of the odor to someone's nose. How might you convince that person of a stronger scientific idea?

Appendix B

Embedded Assessment for 6th Grade Chemistry, Activity 16.1

Examining Your Model of How Odors Move Across the Room
6th Grade Chemistry, Activity 16.1

1. Individually, draw a model that shows how odor moves across the room.



What is the purpose of your model? What might you use your model for?

How does your model accomplish this goal?

What makes a good model?

Use your model to explain how and why odors move across the room.

2. Use the table below to record the **3 most important changes** that you made to your earlier model in order to create the revised model on the first page. For each important change, describe how it helps the model explain the thing you are trying to figure out.

Detailed Description of Change	How does this change improve your model?

3. Do you think your model should explain all the different ways that substances move around like odors or air molecules or should it mainly focus on a specific situation like how perfume odors move in a room?

Why?

4. Does your revised model use the information from your class *experiments, ideas from your classmates and teacher*, *simulations*, or *demonstrations* that you learned about in class?

If yes, how does it use this information? If no, why doesn't it use this information?

5. Is it important for your model to include the information you learned in class like your class *experiments, ideas from your classmates and teacher, simulations or demonstrations*?

Why or why not?

6. Who do you think your model is for?

Someone else thinks that odor moves in a straight line from the source of the odor to someone's nose. How might you convince that person of a stronger scientific idea?

Part II: What else can my model explain- Activity 16.2

7. Choose one of the scenarios in your student book on page 140-142. Write down the phenomenon here:
    a. How does it relate to the model of how smell travels?
8. How could you modify your current consensus model to explain your assigned phenomenon?

Detailed Description of Modification	Why is this modification necessary?

1.	
2.	
3.	
4.	

9. Draw the model below.
10. During your class' discussion, you heard about the other phenomenon that other people had to explain.

    a. Do you think your model could be used to explain the other phenomena?
    b. What changes would you have to make to allow your model to be more flexible?

Appendix C

Embedded Assessment for 7th Grade Biology, Activity 11.1

7th Grade Biology, Activity 11.1

1. Write a convincing evidence-based explanation to answer the question: How and why does everything work together inside my body?

2. What is the purpose of an evidence-based explanation? What might you use your evidence-based explanation for?

3. How does your evidence-based explanation accomplish this goal?

4. What makes a good evidence-based explanation?

5. What are the most important things that you made sure to include in this explanation. Be specific in your answer.

Detailed Description of Item	How does this improve your explanation?

6. Underline your evidence in your evidence-based explanation on the front page. Why is this evidence in your explanation important?

7. Can your evidence-based explanation help you explain some other ways that **any** system works together or can it **only** help you explain this specific system like how your body works together?
Why?

8. Who do you think your evidence-based explanation is for?

Why?

Appendix D

Embedded Assessment Interview Protocol for the Chemistry Unit

Embedded Assessment
Interview Protocol 1/6/13

[Make sure the interviewer has a copy of the students' embedded assessment during this interview. Questions will be asked about the model or explanation product that they have drawn/written on the embedded assessment. It is not necessary to go through the questions on the embedded assessment and have students to explain their responses. The questions asked about the product will help us capture student thinking of the dimensions].

1. What were you trying to figure out with your model?

   Followup:

   - Get more specifics about what about the phenomenon they were trying to model. Ask them to use their model to explain the phenomenon.
     - (Mechanism) How does your model answer the question [use question on embedded assessment, such as "How and why do odors move across the room?"]
     - (Mechanism) What do these [words, numbers, symbols] represent in your drawing? Why did you use them? What are the most important parts of your model? Why?
     - (Evidence) What have you seen or heard (in your life or in class) that makes you think this happens? During the unit? Outside of school?
   - What is the purpose of a model? What could you use a model for?
   - How does your model accomplish this goal?
   - What do you think makes a good model?

2. Did you or your group make any changes from your earlier model to this model? What differences were there between your earlier model and this revised model? Talk about the three most important changes that you made to your earlier model. For each change, tell me how this change helped you better answer the question [put question from embedded assessment, ""How and why do odors move across the room?"]
Followup:

- Push for any individual changes. Interviewer should know the context.
- Push for additions/deletions

3. (Evidence) Think about the various activities that you or your group did in class that helped you to revise your original/initial model. For example, the experiments you may have done, the discussions that you had with your classmates or teacher, the readings you may have read, etc.

    - How does your revised model fit the evidence you collected in this unit? Can you give specific examples from your model?
    - What was the most important thing you or your group did to help you make the changes to your original/initial/earlier model? Please be specific.
    - What was the second most important thing?
    - What did people in class and in your group looked for /suggest changes about? (Evaluation criteria) Why do you think that was?
    - Can you describe how it helped you make the changes you made?
    - How did you know if the information that you got (from the experiments, teacher/classmates, simulations, and readings) was accurate or correct?

4. (Generality) Could you use your model to explain something else? For instance, do you think your model should explain ***all the different ways*** that substances move around like odors or air molecules? OR, should it mainly focus on a ***specific*** situation like how perfume odors move in a room? Why?

    Can add in specific examples and ask students to do this: Let's try using your model of smell to explain these two phenomena.

    Closely related/familiar context – smelling an orange that has been peeled from across the room

    More complex/less familiar context – the smoke detector goes off when you burn your toast.

5. (Audience) Who is the model for? Why—say more? How might……use this model? Is it useful for anyone else?

Consensus Process

- Did everyone in the class agree about how the phenomenon (insert specific phenomenon from model here) worked?
    - Was there a specific thing that people in your class disagreed about? Why do you think people disagreed?
    - Were people in the class able to resolve these disagreements? If so, what did your class do?

- Did you agree with the decision that the class made?
- Did your class end up agreeing at the end of the day?

Appendix E

Embedded Assessment Interview Protocol for the Biology Unit

Embedded Assessment
Interview Protocol 3/**26**/13 (Explanation)

[Make sure the interviewer has a copy of the students' embedded assessment during this interview. Questions will be asked about the explanation product that they have written on the embedded assessment. It is not necessary to go through the questions on the embedded assessment and have students to explain their responses. The questions asked about the product will help us capture student thinking of the dimensions].

1 What were you trying to figure out with your evidence-based explanation?

   Followup:

   - Get more specifics about what about the phenomenon they were trying to explain. Ask them to use their evidence-based explanation to explain the phenomenon.
     - (Mechanism) How does your evidence-based explanation answer the question [use question on embedded assessment, such as "How and why does everything work inside your body?"]
     - (Mechanism) What are the most important parts of your evidence-based explanation? Why?
     - (Evidence) What have you seen or heard (in your life or in class) that makes you think this happens? During the unit? Outside of school?
   - What is the purpose of an evidence-based explanation? What could you use an evidence-based explanation for?
   - How does your evidence-based explanation accomplish this goal?
   - What do you think makes a good evidence-based explanation?

2 (Evidence) What evidence did you underline in your evidence-based explanation? Why is this evidence in your explanation important?

   - How does your evidence-based explanation fit the evidence you collected in this unit? Can you give specific examples from your explanation?

- What was the most important thing you or your group did to help you make your evidence-based explanation? Please be specific.
- What was the second most important thing?
- What did people in class and in your group look for /suggest when making an evidence-based explanation? (Evaluation criteria) Why do you think that was?
- Can you describe how it helped you make your evidence-based explanation?
- How did you know if the information that you got (from the experiments, teacher/classmates, simulations, and readings) was accurate or correct?

3 (Generality) Can your evidence-based explanation help you explain some other ways that **any** system works together or can it **only** help you explain this specific system like how your body works together?

Let's try to use your evidence-based explanation to explain another situation (students come up with another scenario).

4 (Audience) Who is the evidence-based explanation for? Why—say more? How might……use this explanation? Is it useful for anyone else?

5. Did you or your group make any changes from your earlier explanation to this explanation? What differences were there?

- Talk about the three most important things that you made sure to change or add in this explanation. Be specific. How does this improve your explanation?
- Push for additions/deletions

Consensus Process

6. Did everyone in the class agree about [insert specific phenomenon here, i.e. what impact the invader had on the population]?

- Was there a specific thing that people in your class disagreed about? Why do you think people disagreed?
- Were people in the class able to resolve these disagreements? If so, what did your class do?
- Did you agree with the decision that the class made?
- Did your class end up agreeing at the end of the day?

Final Thoughts on Practices

7. What similarities and differences do you see between the models and explanations that you made? Do you feel one (model or explanation) is better at showing phenomenon in science? Why?

- What parts of … make it better than …? (if one is better than other)
- What parts of the models and explanations do you think are the most important?