COLLABORATIVE MODELING IN A MIDDLE SCHOOL SCIENCE CLASSROOM

by

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(Under the Direction of Julie Kittleson)

ABSTRACT

Educational standards have varied over many years. With the publication of the *Next Generation Science Standards* (NGSS Lead States, 2013) and the implementation of *A Framework for K-12 Science Education* (National Research Council, 2012), science education has changed from that of knowledge acquisition to that of meaningful application of science skills throughout all grade levels in both science and engineering fields (NRC, 2012). One of these skills is modeling. Students should be developing, using, and revising models instead of using the model as a form of information consumption. Therefore, the purpose of this study was to gain an understanding about how middle school science students work through a modeling task. Using narrative thinking this study sought to uncover how students go about modeling and what their conversations reveal about their modeling. Findings indicated that students' personal understandings about models play a role in the development and construction of their model. Also, prior experiences with models impacted how students talked about and developed their model. Findings also showed that students had incongruent view of model development and data acquisition and that a lack of interpersonal skills limited advantageous participation. These findings have implications for teachers both in the

elementary and middle school in the way in which educators discuss, use, and teach about models and modeling. Findings in this study also suggest areas for continued research.

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DEDICATION

This dissertation is dedicated to my middle school teaching family. A group of professionals who continually go above and beyond to engage all students every day in every subject. This family continually supports one another through the ups and down that encompasses middle school life. I hope you realize how important you are in the lives of your student's and in the lives of your coworkers.

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CHAPTER 1

INTRODUCTION

Teachers employ a variety of tools to help students engage with science content. Such tools include videos, online games, worksheets, labs, and various hands-on experiences. One tool that is ubiquitous in science classrooms is the model. Scientific models range from cell models in biology to ball and stick models in chemistry to mathematical formulas in physics. The ability to create and use models is an authentic skill that students need to prepare themselves for future careers (National Research Council [NRC], 2012), as a way to develop understandings about complex concepts and to help visualize their understandings.

Developing and using models in science education has been emphasized in the past several years with NRC's (2012) release of *The Framework for K-12 Science Education*, followed by the *Next Generation Science Standards* (NGSS Lead States, 2013). Despite the prominence of models in recommendations for instruction, research indicates that students still have naïve views of modeling (Cheng & Lin, 2015; Grosslight, Unger, Jay, & Smith, 1991; Krell, Reinisch, & Krüger, 2015; Treagust, Chittleborough, & Mamiala, 2002). Findings about students' view of models reveal that "it is important to teach students about how scientists use models in scientific research and to develop students' own competencies for using models in science learning" (Jong, Chiu, & Chung, 2015, p. 987). Even though models and their uses vary in science, the

ability of students to appropriately use models in the classroom is a vital part of science education. Students must possess skills to help them develop, use, and revise models, but educators must have a general idea about how students negotiate the modeling process.

Defining the Problem

The NRC, National Science Teachers Association, American Association for the Advancement of Science, and other partners were instrumental in developing the NGSS and the *Framework for K-12 Science Education*. The *Framework* puts forth a vision for science education that includes science and engineering practices, crosscutting concepts, and disciplinary core ideas (NRC, 2012). Science and engineering practices include eight skills that students should develop while in school, one of which was "developing and using models" (p. 42).

Because modeling has been identified as being important to science education, educators must understand how to provide high quality instruction to help students develop the skills to create, use, and revise models. As a teacher I have noticed a common theme in discussions about models with peers and students. Teachers and students reference models as something that can be touched in three-dimensional space; they characterize models as being a smaller version of the real object. They also view the model as something to help them learn science concepts (e.g., the parts of a cell on a large tangible cell). This observation is congruent with Grosslight et al.'s (1991) finding that students think of models as "little copies" (p. 819). They also found that students do "not clearly distinguish the ideas and/or purposes underlying the model, the model itself,

and the experimental data which would support or refute the validity or usefulness of the model" (p. 819).

Harrison and Treagust (2000) and Michalchik, Rosenquist, Kozma, Kreikemeier, and Schank (2008) both mentioned that students view models as being analogous to a correct answer and that models are to be memorized. Using models in science education is important because students tend only to see the surface value of a model. Providing students opportunities to use and explore models offers students the ability to explore a variety of phenomena and to build on their previous understandings.

When I ask students to build a model, the first thing they want to know is if they can use Styrofoam. They also inquire about the size parameters. The ideas about modeling espoused by my students echo findings from previous research. Researchers have found that students view models as exact replicas (Grosslight et al., 1991; Krell et al., 2015; Treagust et al., 2002). Because students view models as exact replicas, the idea that models can be revised is difficult for students to grasp (Cheng & Lin, 2015). Due to their naïve views, students struggle with understanding what constitutes a model and how to go about modeling science concepts. Researchers and educators must uncover the aspects of modeling that pose the most difficulty. This study addressed that issue.

Why Models Are Important

Providing students with an opportunity to construct and use models in science offers them an opportunity to participate in authentic science practices. Jong et al. (2015) identified the importance of teaching students how scientists use models and how students can use models to develop their scientific thought. Modeling allows students to

explain how their world works (Gilbert, Boulter, & Rutherford, 1998). While models can be beneficial for students, students have naïve conceptions of what models are. These naïve conceptions create a divide between activities in science class and authentic science *practices*. For students to participate in science they need to develop understandings of what constitutes a model and how models are used in science.

Modeling in the K-12 Curriculum

The Framework for K-12 Science Education

The Framework for K-12 Science Education (NRC, 2012) stated that "an explicit model of a system under study can be a useful tool not only for gaining understanding of the system but also for conveying it to others" (p. 92). The *Framework* mentioned the importance of modeling in science education because models help students "develop explanations about natural phenomena" (p. 50).

According to the *Framework*, by the time students graduate from high school they should be able to use models for a variety of tasks, such as the following:

- construct drawings or diagrams as representations of events or systems,
- represent and explain phenomena with multiple types of models,
- discuss the limitations and precision of a model as the representation of a system, process, or design and suggest ways in which the model might be improved to better fit available evidence or better reflect a design's specifications,
- make and use a model to test a design, or aspects of a design, and to compare the effectiveness of different design solutions (p. 58).

The NGSS included these ideas about models and provided specific content and skills students should be involved in at each grade level.

The Next Generation Science Standards

The NGSS were published in 2013, and since then states have been using the information for incorporating engineering and science practices, core ideas, and crosscutting concepts into current state science standards. Modeling is used throughout each grade band and in different content areas. For example, modeling is incorporated into the fourth-grade standards by saying that students need to be able to "develop a model to describe that light reflecting from objects and entering the eye allows objects to be seen" (4-PS4-2). In physical science at the middle school age range, students should be able to "develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials" (MS-PS4-2). High school students should be able to "develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection" (HS-ESS2-3).

The NGSS assume that students' abilities to use and understand models develops in complexity as they get older. Modeling is included as a scientific practice and a cross cutting concept. As students are involved in science classes, they should be developing conceptions of what constitutes a model. They also should also be progressing in the ability to develop, revise, and use a model appropriately within the given task. As students learn more about models and use models in conjunction with science content, it would be beneficial to explore the disconnect between modeling and how students interact with models.

Modeling is an important part of science education, as shown in the *Framework* and NGSS. However, students still have naïve concepts of what constitutes a model and what the modeling process entails. I have been teaching middle school for more than 15 years, and I have noticed that teachers incorporate a variety of models within their classroom and provide instruction on models, but a disconnect persists between what students understand about models and what they are to accomplish with models. Students routinely associate models with being larger or smaller replications of the real object. They also struggle with relating how real-world science concepts are connected to the labs and activities that are done in class. To better understand how to assist students with their understanding of modeling and the modeling process, this study focused on the following research questions:

1. What is the substance of students' conversations as they collaborate during the modeling process?

2. What does this substance reveal about students' use of modeling?

Three important implications for modeling instruction come from this study. First, this study highlighted gaps in students' understandings of models. These gaps could provide information to help teachers be intentional in their modeling instruction. Second, this study provided insight into students' thought processes concerning modeling as they worked through the modeling process. Last, this study identified gaps where new research could be done. Valuable information gleaned from their conversations may be used to enhance science instruction.

Researcher Statement

Here, I present my experiences as the researcher. I am both the teacher and the researcher in this context. My subjectivity brings a unique lens to this study. Being aware of my subjective self means that I am aware of the qualities that affect my research. The SAGE Encyclopedia for Qualitative Research (2008) says that researcher subjectivity "may bias, unbalance and limit endeavors, but they may also motivate and illuminate inquiry" (p. 3). Peshkin (1988) wrote about researchers' understanding, where the "self and subject became joined" (p. 17). He wrote that one must identify one's subjectivity during research and not after the research is done. My life experiences have shaped the way in which I believe science should be taught. These life experiences must be understood, identified, and acknowledged to appropriately study my chosen phenomenon.

I am aware that my role as teacher in my classroom and as a researcher using information from my classroom poses a unique research environment. It is important that make readers aware of the educational activities I have provided my students throughout the year and acknowledge that it could impact my study. Students could possibly use activities, methods, visuals, materials, or directions that were done prior in the year as inspiration for their modeling task. I kept a journal of any modeling related activities we did throughout the year. This practice allowed me to go back and identify any similarities between their model development and class activities. During this modeling activity it was important for me to step back from offering assistance that might skew student conversations and let my students take their own lead and show what they knew and understood.

As I worked through the data it was important for me to separate what I know students could do from what they did during their assessment and what they submitted. Analyzing data after the school year concluded provided that mental separation between student and participant. That separation proved valuable, and as I coded data I began to visualize their actions under their assigned pseudonym.

CHAPTER 2

REVIEW OF LITERATURE

Research in science modeling spans many grade levels and encompasses a variety of types of modeling. This chapter focuses on how models are used in science education, what constitutes a model, and where and how modeling appears within national and state standards and overview of the modeling. The chapter will conclude with an overview of research on modeling in middle school and the theoretical frameworks applicable to this research.

Models in Science Education

In science classrooms at all levels, models can act as a sensemaking tool to help students synthesize complex information (Bailer-Jones, 1999; Baek & Schwarz, 2015; Cheng, & Lin, 2015; Passmore & Stewart, 2002; Shen, Chang, & Namdar, 2014; Treagust et al., 2002). They are also used to introduce new science material to get students interested in new topics within the confines of the classroom (Harrison & Treagust, 2000). Models can be used by students and developed by students to demonstrate understating (Baek & Schwarz, 2015; Shen et al., 2014). Models are used to make connections between what is being learned to the student's life outside of the science classroom (Gilbert, 2004).

Studies have shown that students have preconceived notions about what constitutes a model and how models are used in science (Cheng & Lin, 2015; Krell et al.,

2015; Treagust et al, 2002). Students need to understand that models help scientists "develop an understanding of the natural world" (Passmore & Stewart, 2002, p. 188). Lehrer and Schauble (2012) described school science as being usually taught with the end in mind, making sure students know the material, but that it "often fails to support student learning about the ways that scientific knowledge gets, made revised, and sometimes abandoned" (p. 702). Providing opportunities for students to partake in the modeling process allows them to participate in authentic meaningful science. So, "if we want students to develop a richer conception of models, then it is important for the science curriculum to provide students with more extensive experiences with models and more time to reflect about those experience" (Grosslight et al. 1991, p. 820). The modeling process provides opportunities for students to participate in authentic science "without risking life and property" (Harrison & Treagust, 2000, p. 1016). Providing a variety of modeling experiences, including development, use, and revision, allows students to be involved in authentic science practices.

Gilbert (2004) mentioned that "students commonly find the subject matter of science to be abstract, couched in complex language, and too often of insufficient immediate interest" (p. 115). Modeling can provide opportunities for students to interact with the content and help to foster an interest in science. The difficulty with using models to help foster interest in science is that students have immature conceptions of what constitutes a model. They frequently think that models are "just like the real thing" (Grosslight et al., 1991, p. 804). Not understanding what a model is causes difficulties to arise as students attempt to construct and revise their model. The ability to use a model to

explore phenomena offers opportunities for students to realize that models change as new information is learned and that science in tentative. Modeling offers students an alternate modality to explore science content within their comfort zone and academic ability. Providing opportunities for students to develop or use models in class allows students to participate in authentic science practices. Authentic science practices could make science meaningful for students. Since studies have shown that students struggle to identify what constitutes a model and how models are used, it is important to identify the various types of models.

What Is a Model?

Literature from the past 20 years provides a variety of definitions of what constitutes a model. Gilbert et al. (1998) said, "Models can be of ideas, objects, events, systems or processes" (p. 92). Others refer to models as tools, something that helps to explain concepts (Bailer-Jones, 1999; Cheng, & Lin, 2015; Treagust et al., 2002) or representation of concepts (Lee, Chang, & Wu, 2017; Ornek, 2008). Models can also be used for understanding difficult concepts, making predictions, and making connections between variables (Bailer-Jones, 1999; Passmore & Stewart, 2002; Shen et al., 2014; Treagust et al., 2002). Models can be used as an explanatory medium for complex systems (Baek & Schwarz, 2015) or to illustrate a component of that system (Shen et al., 2014). Entire systems can be represented, or a small subset of that system can be represented. Many researchers describe a model to help understand phenomena and as a way to make predictions about what might happen in the future (Jong et al., 2015; Lee et al., 2017; Passmore & Stewart, 2002; Schwarz et al., 2009). What is included or

excluded, to some extent, in the model is irrelevant if the model serves its designed purpose and there is an understanding or connection between the model as it is created and its real-world counterpart. Gilbert (2004) described this connection as a bridge between a person's lived experiences, the real world, and scientific explanations, which include the model.

While definitions of models are copious, some continuity can be found in the classifications of models. Each branch of science has certain types models that they prefer, and each model type can be used within the various branches of science. No model is tied to one branch of science. This next section describes the most commonly used types of models across all branches of science.

Mental Model

Mental models can be described as a personal internal representation created by an individual or within a group of people (Gilbert, 2004). For a mental model to be created within a group, the group must come to a consensus as to how the model is used and the general idea of what it looks like, even though no physical representation of the model exists. Harrison and Treagust (2000) described a mental model as a model generated individually internally within the mind as individuals grapple with new and complex information.

Physical Model

Researchers have a variety of names for models that can be touched or physically manipulated. Ornek (2008) described models that others can use as a physical model. Gilbert (2004) called a model that "is three dimensional and made of resistant material"

(p. 118) a concrete model or a material model. Harrison and Treagust (2000) referred to models that "are used to depict colors, external shape and structure" (p. 1012) and can be touched and manipulated as a scale model. Physical models provide an opportunity for students to tactilely interact with a replication of the concept, for example, a foam representation of a cell with organelles that may or may not be removed.

Symbolic/Mathematical Model

Chemical formulas and symbols and mathematical properties such as expressions and equations are frequently described as symbolic models (Gilbert, 2004). Symbolic models utilize "the conventions of math" (Gilbert et al., 1998, p. 92). Harrison and Treagust (2000) described symbolic models as formulas and equations but indicated that these models are not reality but require an interpretation to understand their meaning. These models are used to help visualize relationships between different components.

Visual Model

Two dimensional objects or representations that cannot be manipulated are frequently described as visual models. Harrison and Treagust (2000) described maps, diagrams, and tables as being models because they "represent patterns, pathways and relationships" (p. 1016). This definition is comparable to Gilbert (2004), when he said that "visual models make use of graphs, diagrams, and animations" (p. 118). Visual models are frequently used in textbooks as a descriptive and explanatory tool.

Simulation

A simulation model is used to help comprehend "complex and sophisticated processes" (Harrison & Treagust, 2000, p. 1016). The unique aspect of simulation models

is that they allow students to experience phenomena “without risking life and property” (p. 1016). Simulations frequently utilize different types of technology to recreate natural phenomena in an explorable format to make connections in the real world.

Analogical Models

The final type of model is an analogical model. These models can incorporate a variety of the other models described but include an analogous relationship to something the students understand. Harrison and Treagust (2000) said, “Analogical models comprise the scaled and exaggerated objects, symbols, equations, and graphs, diagrams and maps, and simulations that facilitate scientific communication” (p. 1012). Gilbert et al. (1998) described an analogical model as something created by an instructor to aid students’ understanding. Analogical models take something abstract and make it analogous to something students are familiar with to facilitate comprehension. Most of these models are given to students to use as visualization tools, but the new standards have students interacting with models in a variety of different ways.

Modeling

As students develop science and engineering skills related to modeling, they are exposed to the modeling process, either explicitly or implicitly. Modeling is “the process of constructing models” (Lee, Kang, & Kim, 2015, p. 234). The process of modeling has several steps and, if necessary, steps can be repeated. Halloun (2007) described the process of modeling starting

> with the construction of a tentative model followed by the collection of appropriate empirical data that will be analyzed to test the validity of the model

> and subsequently make the appropriate judgment as to the acceptance, refinement or rejection of the model. (p. 29)

Nelson and Davis (2012) described the modeling as a nonlinear process that involves model construction, use, evaluation, and revision. They did not describe it as a "process," but their definition is reminiscent of the modeling process, in that a model is not a fixed, permanent object, rather something that must be revised as new information is learned. Educators should preserve the cyclical nature of modeling and teach that the first model is not the final model but that models are revised and reevaluated (Lehrer & Schauble, 2000).

In education, model construction is used to help students develop foundational conceptions of scientific ideas. As more information is learned and understood by the students the created model is reconstructed and theory development begins (Halloun, 2007). Oğuz (2007) described the building of models or model construction as being a process that incorporates "formulating questions and seeking answers through observation, interpretation, problem solving, and critical thinking" (p. 198). Oğuz went on to explain that students struggle to develop mental representations, but model construction provides an instructional method that promotes the construction of models for conceptual understanding. These models can be reconstructed as new information is learned. The modeling process is a way for students to "attempt to explain reality through a creative process where scientific knowledge is used as a mediating from of reference" (Machado & Braga, 2016, p. 824). Providing students opportunities to interact with a

variety of models and opportunities for modeling helps to further student understanding around a variety of scientific concepts.

Modeling in the Standards

A Framework for K-12 Science Education (*Frameworks*, NRC, 2012) and the NGSS both emphasized modeling. Both called for students to be a part of the modeling process; creating, using, and revamping their model instead of using the model as a way to consume information. The following sections describe how modeling is presented in both documents.

The *Framework*

The *Framework* was developed to help move science education into the 21st century by creating a new vision of science education. This vision included science and engineering practices, crosscutting concepts, and disciplinary core ideas. Cross cutting concepts are concepts that are interchangeable between the different science disciplines, such as physics, chemistry, biology, and the earth sciences. Science and engineering practices include using data as evidence for supporting a claim, analyzing data for argumentation, collaborating effectively with others, and developing scientific testable questions. Disciplinary core ideas can be described as the main science content knowledge in the different disciplines of science that students should know as they graduate high school. These core ideas are built upon throughout the students K-12 experience.

The *Framework* is an outline, or a guide, for teachers, curriculum designers, and standards developers. It suggests content and skills that students should learn while in

school (p. 42). With respect to skills, the *Framework* identifies the following skills to be addressed in the classroom:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

To help students develop these eight skills from the *Framework* seven cross cutting concepts were identified to help students develop views of the world that were coherent and based in science (National Research Council, 2012, p. 83). The cross cutting concepts are as follows:

1. Patterns
2. Cause and effect
3. Scale, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation.
6. Structure and function
7. Stability and change

With respect to modeling, the *Framework* discussed that models can be used to help with understanding, but is also used for sharing information. Models help students develop explanations for everyday phenomena with the hope that they someday can use their modeling skills on new and abstract concepts. Providing students opportunities to engage in scientific practices, such as modeling, aids in the understanding of crosscutting concepts and helps to make connections between science content and students' lives.

By the time students graduate, they should be able to use models for a variety of tasks, such as

- construct drawings or diagrams as representations of events or systems,
- represent and explain phenomena with multiple types of models,
- discuss the limitations and precision of a model as the representation of a system, process, or design and suggest ways in which the model might be improved to better fit available evidence or better reflect a design's specifications,
- make and use a model to test a design, or aspects of a design, and to compare the effectiveness of different design solutions. (NRC, 2012, p. 58).

Students are gradually exposed to models and modeling practices throughout the K-12 grades to help them develop these competencies.

The Next Generation Science Standards

The emphasis on modeling also appeared in the NGSS. When the NGSS were published in 2013, states started using them for incorporating engineering and science

practices, core ideas, and crosscutting concepts into current state science standards. Because modeling is now an explicit and integral part of the science curriculum the content, students must develop understandings of what constitutes a model and how models are developed and used. As students develop conceptions of models, they also should also progress in the ability to develop, revise, and use models appropriately.

Modeling in Middle School

Typical middle school students are in sixth, seventh, and eighth grades and range in age from 11 to 14. At this level science becomes a core content area, as opposed to elementary school where students are exposed to science in a limited format and time frame. The shift from an infrequent class to a core subject that includes abstract concepts and includes high stakes assessments causes some students to develop a dislike of science. This dislike often stems from the vast amount of content students are expected to learn. Modeling provides a way for teachers to engage students in skills that can make science more meaningful. In order to understand what has been done with modeling at the middle school level, an overview of studies with middle school students is useful.

The studies included in this section have included students in the typical age and/or grade range for middle school. Study designs that center on middle school students and their modeling prowess range from questionnaires (Cheng et al., 2017; Lee et al. 2015; Lee et al., 2017; Treagust et al., 2002), to interviews (Grosslight et al., 1991; Schwarz & White, 2005), short answer questions (Pierson, Clark & Sherard, 2017), pre and posttests (Bati & Kaptan, 2015; Cheng, Lin, Lin, & Cheng, 2017; Schwarz & White, 2005), student created documents (Komis, Ergazaki, & Zogza, 2007; Schwarz & White,

2005), curriculum changes (Cheng et al., 2017; White, 1993), and video and audio recordings (Pierson, Clark, & Sherard, 2017; Schwarz & White, 2005). From these studies a variety of findings emerged.

Grosslight et al. (1991) and Treagust et al. (2002) found that middle school students think models are tiny replicas of a much larger object or concept. Students also showed a preference for three-dimensional models and understood their purpose but struggled to identify other forms of models and frequently got confused between scientific equipment and models (Lee et al., 2017; Grosslight et al., 1991). It was also noted that students showed that they could create a model that was slightly abstract from the original concept, but students needed a reason to create the model (Schwarz et al., 2009).

Model development is difficult for middle school students because models are viewed as a correct answer instead of something that could change depending on new information (Schwarz et al., 2009). Using a survey Treagust et al. (2002) found that students understood that models can change as science changes, but they do not grasp the connection between the model and the development of scientific ideas. Cheng and Lin (2015) found that even those considered “good” students may struggle with developing a model. Schwarz and White (2005) found that by using a Model-Enhanced Thinker Tools (METT) Curriculum students could identify models and understood that models have multiple uses. They found that participants were “less successful at promoting understanding about creating, evaluating, and revising models” (p. 194). By analyzing student drawings and focus group interviews Schwartz et al. (2009) found that students

could revise their models and describe how their models were changing by including more scientific information. During interviews researchers found that students do change their model based on new information, but during lessons students had to be prompted to revise their models. In order to lessen students' confusion when working with and developing models, some researchers studied the use of learning progressions centered around modeling to help with students understanding of models.

Several researchers have looked at the modeling curriculum and how students can progress in their understanding of models. Cheng, Lin, Lin, and Cheng (2017) used both a treatment group with a modeling curriculum and comparison group with traditional curriculum. They found that by using a scaffolded modeling curriculum students were able to build more complex and sophisticated models than were students with the traditional curriculum. Cheng et al. suggested that a modeling curriculum that includes reflective thinking along with modeling improves students learning in "their views of scientific models, as well as developing explanatory models" (p. 214). Pierson et al. (2017) wanted to further explore learning progressions with a modeling curriculum. Through their research they found the when using representational models' students had a much higher understanding when it came to written reflections about models than they did with model construction. Overall, they found that middle school students were able to partake in high level modeling across all progressions. To have high levels of model understanding it was important they students moved through various types of models.

While some researchers focused on independent student understanding of models and modeling, others focused on the collaborative impact of modeling in the science

classroom. Lee et al. (2015) examined collaborative modeling and students' different approaches, deep learning or surface learning. Lee et al. utilized Biggs' (1993) description of the two learning approaches: surface learners are focused on rote memory while deep learners are more likely to make connections to previously learned information. In looking at students' collaborative conversations, they found that students who used a deep learning approach in their discussions provided opportunities for other students to build on their understandings of model development. "Individual learning approaches not only affected individual learning but also influence the group modeling learning process" (p. 251). Scaffolding and argumentation were also positively impacted when students used a deep learning approach in collaborative conversations centered on modeling.

Komis et al. (2007) also studied collaboration between students. While they considered their participants high schoolers, the two participants were 14 years old, which makes this study applicable for this section. They examined these two students who worked collaboratively on an activity creating concept maps on plant growth. One concept map was made using prelabeled index cards and the other was made with an online program. They found that students struggled to make connections between the processes of growth and photosynthesis; the two were viewed separately. Their participants tended to focus on the reactions that occurred during photosynthesis instead of connecting the chemical reactions during photosynthesis to plant growth. They noted that their participants were reliant on the facilitator more so then each other due to students not having familiarity with either task. As students work on activities in the

classroom, they inevitably glean information from each other. Collaboration can help students to develop their scientific ideas and to act like scientists.

Research has shown that students can use a variety of models, but unless students understand how models and the modeling process works, scientific modeling has little value. Some technology programs help students develop modeling knowledge. When researchers and teachers collaborate on model-based activities student understanding increase. Not all classrooms have access to technology-based programs, knowledgeable researchers, or a sophisticated understanding of models themselves. Teachers and researchers must have a glimpse into students' thought processes when they are put into a situation developing and using models. This glimpse could help teachers structure their lessons for greater student understanding.

This section has shown the variety of methodologies employed to study students' understanding of models and modeling at the middle school level. In summary, students viewed models as tiny copies (Grosslight et al., 1991; Treagust et al., 2002), and students preferred three-dimensional models and struggled to identify other forms of models (Grosslight et al., 1991; Lee et al., 2017). Modeling for middle schoolers was difficult, as they tended to view models as correct answers (Schwarz et al., 2009). While students understood that models can change (Treagust et al., 2002), they struggled to make changes to their own models when new information was gathered via METT curriculum (Schwarz & White, 2005). When interviewed Schwartz et al. (2009) found that students could change their model when new information was gathered. Several researchers focused on learning progressions in order to mitigate some confusion students had with

modeling. Cheng et al. (2017) and Pierson et al. (2017) found that having a scaffolded curriculum in conjunction with time for reflection helped students improve their understanding of models and modeling. Other studies showed that collaborative modeling can aid in students' understandings (Lee et al., 2015). If students had a deep learning approach to modeling in a group, they could provide a scaffolded conversation to help other students progress in their understanding of modeling (Lee et al., 2015). For students to collaborate successfully they had to be familiar with the task at hand (Komis et al., 2007). If students were given activities that they were not familiar with, they tended to look toward the facilitator for assistance rather than to their peers (Komis et al., 2007).

Theoretical Framework

The ability to work effectively in groups to foster learning within the group is an important part of a student's life while in school and after school. Collaboration within the educational system and beyond is considered a 21st century skill (Larson & Miller, 2011). Students need to have the skills to be able to communicate with others face to face and on the internet. The *Frameworks* also stated that "science is fundamentally a social enterprise, and scientific knowledge advances through collaboration" (NRC, 2012, p. 27). It goes on to discuss how these collaborative interactions can be both formal or informal and can be face to face or through digital means. Collaborative learning can be described as when "two or more students jointly work out a single solution to a problem" (Linn & Burbules, 1993, p. 92). Knowing that collaboration is a 21st century skill and an important part of scientific knowledge acquisition and growth, it seemed best to view this study through the theoretical lens of social constructivism.

Social Constructivism

Social constructivism is founded on the premise that learners construct knowledge as a group not individually. Driver, Asoko, Leach, Scott, and Mortimer (1994) described constructivism as when "knowledge is not transmitted directly from one knower to another but is actively built up by the learning" (p. 5). Social constructivism suggests that this construction of learning is done within the social context. Driver et al. (1994) went on to say that "scientific understandings are constructed when individuals engage socially in talk and activity about shared problems or tasks" (p. 7). In social constructivism learning involves talking and interacting with peers on the same task.

Social constructivism aligns with student-to-student collaborative learning in that students must work together to construct their knowledge. Collaborating with peers is an important aspect of a student's education because no matter the future career of the students they will need to work together and accomplish tasks. Social constructivism and collaboration both rely on a group of individuals to share ideas, thoughts, and questions. Learning then becomes a social activity taking place outside of the person. For collaboration to be effective students need to have the necessary skills and personal knowledge to accomplish the given task (Linn & Burbules, 1993). As students work together and share knowledge and construct new knowledge, they then progress in their own individual learning, which then can contribute further to the group's knowledge construction. When students work together, the process is not orderly, but inherently disorderly. The main goal is for students to have a deeper understanding of their learning (Fosnot & Perry, 2005).

Bruffee (1999) said that “collaborative learning assumes instead, that knowledge is a consensus among the members of a community of knowledgeable peers – something people construct by talking together and reaching agreement” (p. 3). As students work in groups, they draw on their personal knowledge to aid in the group’s knowledge construction. If the group lacks appropriate knowledge, then group learning fails (Linn & Burbules, 1993). When students work together in a group, they must be amicable and be able to offer opinions, advice, or information. A study done by Oliveira and Sadler (2008) found that when students work in groups there needs to be more than just polite conversation. They found that students needed to challenge each other for greater detail in their explanations. They also found that too much negative interaction hinders understanding. Linn and Burbules (1993) suggest that for collaboration to succeed students need to be able to successfully communicate their ideas and to be able to help other group members understand why their ideas are valuable for the current task.

While these studies provide valuable information as to how students view models and how to progressively help students understand model development, they lacked a foundational understanding of what happens when students are given a modeling task. The field lacks understanding of the nature of student conversations as they work together on developing and using their model and how these conversations impact their modeling progression.

CHAPTER 3

METHODS

The purpose of this chapter is to describe the qualitative research methodologies I used to determine the substance of students' conversations during their collaboration and what the substance of conversation reveals about students' use of modeling. Using the qualitative approaches described in this chapter provided an opportunity to understand what transpired when students were tasked with developing a model that can be used to collect data. This chapter will cover methodology, participant selection, data sources, the context of the study, and data analysis.

Methodology

Since little is known about how students collaboratively go about modeling, it was important to examine students' spoken words. A qualitative case study was most appropriate for interpreting students' conversations and gaining insight as to how they collaborated during a modeling task. Case studies allow researchers to explore "a phenomenon within its context using a variety of data sources" (Baxter & Jack, 2008, p.544). Since this study examined two groups of participants, a cross-case comparison was also conducted. Having multiple cases allows for the researcher to examine each case or to compare cases. Baxter and Jack (2008) suggest that it can be difficult to present findings from a case study in a coherent manner, and they go on to suggest that telling the case as a story that is to be read. To make sense of both cases, I analyzed them using a

narrative analysis framework. In order to understand how students used modeling, I also completed a thematic analysis.

Participants

Participants in this study included eight students in one seventh-grade life science class. The study took place during the spring semester of 2019. The students in this class mirrored the demographics of the county.

For this study, I acted as both teacher and researcher. All students in my class and their parents/guardians received an invitation letter and permission forms describing the study and requesting they consider participating in the study. An e-mail was also sent home to parents making them aware of the letter that was coming home. As envelopes were being passed out to students, I discussed with the students that participation was voluntary and it would not impact their grade or their personal standing with me or within the class. I also mentioned that all students whether they participated or not would still be completing the same assessment activity. Students were also notified that they would be audio and video recorded, any work that they created would be examined, and I might interview them if I had questions stemming from the videos. I reinforced multiple times that this participation was voluntary, and they were not required to participate. If they chose to participate along with their parents' permission, they could change their mind without any repercussions. I also discussed what a pseudonym was and how each student who can participate would be given a pseudonym and only I would know the identity of each participant. We also discussed what a transcript is and what constitutes identifiers.

We discussed these definitions so they would know that identifying information would be removed from the transcript, further protecting their identity.

Ten students returned all necessary permission forms. Purposeful sampling was done since participants were chosen based on their consent and their parent/guardian's consent. After consent was gained, all students completed a warm-up activity to assess their knowledge of models (Appendix D). These questions focused on what students understood about models, such as what a model is, why and how scientists use models, and what does modeling process mean. Students were then identified as having one of four views of modeling. During the unit prior to the application assessment I observed and noted which eligible students could actively work together and be able to articulate their thoughts in an effective manner. Of those 10 students who were eligible to participate only eight were needed for this study. The eight students were then divided into two groups of four based on their modeling understanding from their answers to the warm-up questions and their ability to work in groups. The warm-up answers were coded, and students were assigned a number based on their views of modeling; additional information will be provided in the data analysis section. I attempted to group students with different views of modeling together in hopes of having two groups of students with varying thoughts on models and who would effectively work together to accomplish the application assessment. Having two heterogenous groups of four participants supplied the data needed to respond to my research questions. Two groups were agreed upon because one group of four may not provide the data necessary to draw conclusions and more than two groups of four may have generated an overwhelming amount of data. These eight

students were assigned a pseudonym from an online random name generator, and after all work was submitted names were removed from documents and replaced with the pseudonyms.

Data Sources

I first collected data from participants in the form of their responses to a series of questions centered on modeling that was done as warm-up. I developed these warm-up questions to gage their thoughts or understanding of models and modeling. These questions were based on discussion questions I had used in prior years when talking about modeling and models within the classroom. I always started with what they think a model is to get past the supermodel, airplane, car, and train response. From there students tend to think about models as they pertain to science. I similarly made the distinction between models and models in science in their warm-up questions. Using these questions in prior years had elicited a variety of response about what students thought or understood about models. The information gathered was used as baseline data to understand students modeling knowledge. Students were assigned a number based on the answers they provided that coincided with a view of modeling: there can be more than one model/used for different purposes (1), models look the same (2), models help explain (3), models can change (4).

This source of data was informative because it provided insight into students' thought processes surrounding models. Students had not been exposed to any of the stereotypical physical models in science during the year of this study but were exposed to a variety of analogous models, mathematical models, conceptual models, and

simulations. Warm-up information was used to group students who have dissimilar conceptions of models together. This step ensured an authentic flow of student conversations during their application assessment, and the ideas surrounding their model development are not sidelined by a student who may have had greater modeling knowledge versus that of a naive modeler or majority rule.

The second source of data I collected was the audio and video recordings of the eight students (two groups of four students) who participated in the summative ecology assessment. Each group was on opposite sides of the classroom, and each group had a camera focused on them. Cameras were positioned to capture the group and their workspace as they worked on their application assessment. This assessment happened over five class periods and one morning before school started. Additional time was offered for all students in this class. One of the two participant groups one came in early to work on their assessment. For both groups this time amounted to roughly 11 hours of audio and video. I transcribed the audio into transcripts for each group. I utilized FTW Transcriber software and the infinity foot pedal to aid in the transcription process. Videos were used to verify who was speaking and to read lips if spoken words were difficult to understand. Video was also used to note what students were referencing if they were not specific with their words. Objects that students held up or pointed to were noted in brackets within the completed transcript.

The final source of data for this study was documents created by both the students and I. I kept a journal of activities and discussions that occurred throughout the year as it pertained to modeling. This journal was then used to identify any possible connections

from the students' speech to things done in class prior in the school year. Students' application assessment documents, such as rough drafts, project proposals, collected data, mathematical representations, and their models were also analyzed to explore commonalities between the two groups' work. These documents were also examined to connect what students said with what they wrote and created.

Context

District

This study took place in a suburban school district in the Southeastern United States. County demographics were as follows: 1% Asian, 5% Black, 43% Hispanic, 49% White, and 2% multiracial (Georgia Department of Education website.). Twenty-four percent of the students within Reed County Schools (pseudonym) are considered economically disadvantaged (Georgia Department of Education website.). Reed County has 33 schools, of which eight are middle schools. Reed County Schools had a mission of "character, competency, rigor…for all."

School

A suburban school in its inaugural year was used in this study. The school demographics were as follows: 0.9 % Asian, 4.9% Black, 24.6% Hispanic, 65.4% White, and 4.2% multiracial (Georgia Department of Education website). This school had two science teachers per grade level, one gifted teacher and one on-level teacher. In sixth grade students take earth science, in seventh grade they take life science, and in eight grade students can take eighth-grade or ninth-grade physical science. Because it was the school's first year, faculty, staff, and students had the unique opportunity to set the tone

for the new school with a focus on innovation. This situation provided an encouraging and supportive setting for students and teachers to try a variety of classroom activities and assessments.

The science department at this school consisted of six science teachers and three special education teachers. The department planned together a few times a year to identify skills that can be addressed vertically throughout the year. During these meetings it was identified that the department did not have stereotypical physical models (e.g., a plastic cell), so students had not been introduced to typical physical models often associated with science. The science department also had no textbooks. Teachers were responsible for using the state frameworks to develop what they did within the classroom. Instruction within each classroom varied: Some teachers relied on electronic slideshows with slotted notes, some were more hands on, and some combined both approaches. Due to the lack of materials within the science department teachers had to be creative and structured and planned hands-on activities to be highly engaging yet cost effective. Teachers typically planned lessons or units together, but each teacher has autonomy within their classroom. In prior years the other seventh grade teachers and I worked very closely to create lessons and assessments. The school year in which this study took place was slightly different in that, while we shared lessons plans and ideas, we did not plan new units together and ended up several units apart by the end of the school year.

The school that participants attended during this study was a one-to-one school, meaning that each student was issued a Chromebook to use at school and at home during the school year. Teachers plan lessons that used the Chromebooks to enhance their

lessons not to provide digital instruction. These devices were collected at the end of the school year. Students were responsible for the care of both the Chromebook and the charger.

Classroom

The classroom used in this study was not a lab classroom, meaning we had no counters, demonstration station, sink, or storage. There was a lab available for middle school science labs to use, but it was in a different section of the school and was not used unless a sink was needed for an activity or lab. Partway through the year the school acquired a variety of lab tables from a technical school that was undergoing renovations. I was able to obtain lab tables that were two different heights. Some tables used chairs, and other tables were tall enough to allow students to stand and work. This setup allowed students the options to work where they were most comfortable. Some students chose to stand because they liked the option to move in their spot. Others preferred to sit and work. These tables allowed students to work in groups of three to six students, depending on where they sat. Students worked on a variety of activities both independently and collaboratively within a variety of different size groups.

The classroom also contained a fish tank and a wide variety of specimens that students were able to examine using the class microscope or a variety of magnifying glasses. Books were prevalent within the classroom, most of which contained a variety of science topics, such as insects, migratory birds, or reptiles. Many of these books were library books that had been deleted from circulation. Lockers were not used within this school, so all students kept their bookbags with them all day. The majority of classes had

between 28 and 30 students. The number of students and bookbags provided logistical difficulty on lab/activity days. To work around the number of bodies and bags I developed several ways of distributing lab/activity materials. I frequently used disposable plastic drinking cups, large plastic bins, and small milk crate type bins. When activities/labs used breakable or expensive supplies, students would move around the room visiting each station and completing the activity in stages. The use of cameras in this classroom was not new for me or my students. Earlier in the year I participated in a county-level professional learning where cameras were used to videotape several teachers carrying out a lesson within classrooms around the county. I volunteered to participate and had one of my classes videotaped. While the class used in this study was different, having cameras and equipment in the room was not new or novel to students within any of my classes.

Instruction

Instruction within my classroom varies. Students work in groups and independently, depending on the content and the place within a unit. For example, students may work in groups to solve a problem or explore a phenomenon as an introduction to a new unit, but toward the end of the unit students work independently reviewing or reinforcing information before an assessment. Depending on the unit, assessments were done independently or in groups. Rarely do I conduct whole group instruction. If I do provide instruction to the whole class, I frequently stop and have students discuss. Additionally, I try to link confusing or abstract content to experiences or things they are familiar with. When I started teaching over 15 years ago, teachers were

viewed as the giver of knowledge. Now I view my role as helping to facilitate knowledge acquisition by providing engaging activities and lessons in an attempt to get students interested in the various aspects of science.

Curriculum

The content students were exposed to was developed over many years by a group of science teachers, including myself, at a prior school using the state standards as a guide. Throughout the school year students learned about cells, classification, prokaryotic and eukaryotic organisms, natural selection, and evolution. The year ended with a unit on biomes and ecosystems and food chains and food webs. Information and activities/labs were changed or added as the years and standards evolved and new material was learned. Teachers are responsible for researching new and updated scientific information or taking additional college classes to advance their science knowledge. Additionally, teachers are tasked with working in collaborative content groups to plan and develop units, lessons, and assessments.

Throughout the school year students used or were exposed to a variety of models, none of which were scientific physical models except for a globe. We used a globe for a discussion of latitude and longitude for a biome activity/lab. The following section reviews the various models and modeling activities students participated in during the school year.

We started off the year by looking at the process scientists go through as they try to answer questions related to science. Students watched and analyzed the processes the MythBusters go through to answer questions. Special attention was paid to drawings,

alterations, variations, and the MythBusters final design. MythBusters is a science television show that has the hosts test a wide range of myths. The class discussed why there were various models of the same concept and why models were altered during testing. A discussion of what constitutes a model ensued, and we discussed how a model is not always something you build that looks like the object in question. We discussed that models could be diagrams, simulations, charts, webs, or analogies. These discussions tended to occur each time we used a different type of model in class. Later in the year to introduce students to the concept of homeostasis, we used an online program (Gizmos) that allows students to model what would happen to the human body during a variety of circumstances. Figure 3.1 shows a screenshot of the Gizmos homeostasis lab. Students discussed why using a model was appropriate for this concept. We also discussed what type of data could be collected from this activity. Students examined the tables and charts that provided a mathematical visual representation of what was happening during the simulation. During the homeostasis lab the virtual person in the lab also experiences visual symptoms of maintaining homeostasis, such as sweating, shivering, and heat stroke. We talked about these visual attributes as observational data and contrasted it with our mathematical data.

After studying what constitutes a living thing, we started to discuss how scientists classify those living things. The state standard requires students to be able to examine historical models of classification and understand prior classification methods compared to modern day classification methods. Students researched various time periods and the scientific tools available during those periods to understand how and why the

classification of organisms changed over time. Students then had to determine the current classification system and the reasoning behind modern classification. A digital model of the evolution of classification was found online. These different drawings were referred to as models. Students' understanding was assessed by identifying various models of classification and explaining how and why they had evolved.

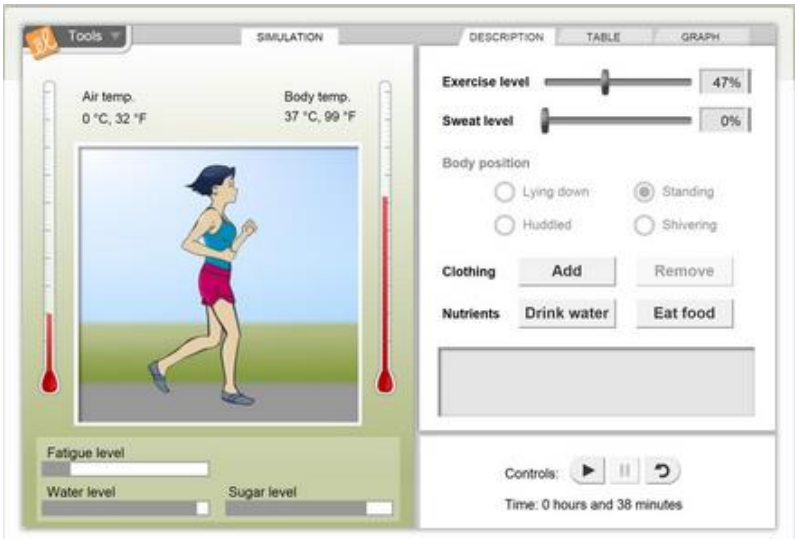


Figure 3.1. Gizmos homeostasis lab.

Students were also tasked with developing their own model of classification with a given set of organisms and defending their method of classification. To practice model development, students created models of classification in groups with familiar objects, such as food (Figure 3.2). They then practiced defending their model of classification by arguing why their method of classification was correct. See Appendix A for the accompanying handout.

Figure 3.2 Food classification

As students worked on this in-class activity, they were told that they would be doing it again with a variety of living organisms for their application assessment. Application assessments are standards-based tasks that students are given, either individually or as a group. They typically occur after a content assessment, which assesses students' basic content knowledge. Their application assessment occurred several days later, and students had to develop a model of classification using a set of organisms. An example of an application assessment can be found in Appendix B. This application assessment was created by a team of seventh-grade life science teachers using online information from Science Learning Hub, a website that contains educational resources, and the teachers own created information. In this assessment students were given an envelope with a selection of organisms on laminated cards and a description of each organism. They then had to develop their own model of classification for the organisms given. After they finalized their model, they had to defend their model and explain why their model made sense using evidence from their model development. Not

all model-based activities required model creation. Some activities used models to explain concepts that are difficult for students to understand.

During the unit on cells and cell processes, the concept of why cells are so small is typically difficult for students to understand. In order to help students understand cell size, we went down to the lab room because we needed a sink. Once in the lab room students obtained three different cubes of agar made with phenolphthalein cut into various sizes with different surface area to volume ratios. The cubes were soaked in sodium hydroxide. When phenolphthalein encounters sodium hydroxide it turns pink. After a set amount of time students cut each cube in half and measured how far the phenolphthalein diffused into the cube. The intention was for them to notice that the smallest cube was almost completely pink. Students measured the length of the pink inside each cube. We referred to these numbers the students gathered as data. Students took their data to their math teacher, who worked with them on calculating the surface-area-to-volume ratio. This activity provided students the opportunity to see why cells are so small. Throughout the year various labs/activities I assigned involved a variety of math concepts. The math teacher on my team would then help students work through the math portion of the activity/lab. This approach helped students make a connection between math and science and realize that their subjects are not done in isolation.

To assess students' understanding of cells and cell process, the standards ask that students develop a model and explain how the parts of a cell aid in various cell tasks. To start the development of their cell models I had students identify their favorite place (e.g., Target) and then identify people, places, or things within their favorite location that

perform the same function as organelles or processes within their cell. Students are then assigned the application assessment, and they make an analogous model of their cell using images or descriptions from parts of their favorite place. Teachers and students referred to what they are creating as a model.

Sometimes we physically modeled various concepts. One example required each student to embody a different version of a type of bird. Weather or environmental occurrences would cause an organism with the less desirable traits to die out. Other times these traits would be beneficial, and the organisms could reproduce. This activity provided a visual for students to see how organisms and their populations change over time.

Knowing that students would be collecting data during the next several units, natural selection and ecology, we spent time discussing what data was and what to do with data that was collected. Again, a discussion ensued of what could be considered data. When we gathered information from our model that was in number form, we called this mathematical data. We contrasted mathematical data with observational data and again discussed the difference between the two. After a quick warm-up where students were given numerical data to graph, it was quickly apparent more focused instruction was needed. An examination of the given data sets occurred, and we discussed what those numbers meant and how that data could be presented in a more informative manner. We then practiced graphing and had discussions on why information is graphed over the next several days as a minilessons within our larger lessons. It is important that students understand that graphs provide a visual representation of numerical data, and it can show

connections between different factors. The application assessment for their natural selection unit required students to model population change using marshmallows of various colors and a white background. Because students were carrying small objects, we used plastic cups to transport materials from their acquisition station to their spot within the classroom. Students then had to graph mathematical data that was collected during their assessment to show how the marshmallow populations changed over time. Students displayed varying levels of confusion with understanding how to graph the change in populations. As a wrap-up for their assessment students had to discuss and write about how a model was not like real life and why models are used within the science classroom.

During our unit on ecology students had to understand how energy flows within an ecosystem. Students completed a population sampling activity to make the connection between how the number of organisms in each energy level determines the health of an ecosystem. We talked about why we would practice population sampling on rabbits and foxes using beans, plastic cups, and bags within the classroom as opposed to a biologist observing populations in a forest. Students had to collect data on the number of organisms within the population during various years. Students then had to take the numerical data that was collected and create a mathematical representation of that data. The final application assessment of the year was the one that was used in this study. Students were asked to develop a model that show how a community of organisms change over time as resources and populations fluctuate (Appendix C). Students were given five class periods and one morning to collaborate with their peers to determine how they were going to construct their model and how they were going to provide evidence

that populations change within an ecosystem. This evidence was to come from mathematical data they collected from their model. Collecting data from their model was a phrase used throughout the year when students were asked to collect some form of mathematical information from their model. During the school year students had developed models pertaining to classification and cell structure and function. They also collected data from models on cell size, natural selection, and ecology. While they had not collected data from a model they developed, they did have experience with model development and data collection from a given model. This study provided an opportunity for students to attempt to develop a model and collect mathematical data from their model, which was a new experience for the participants. I chose to set up the activity in this manner so model development would be as authentic as possible.

The activities described here provide an overview of the modeling activities done within my classroom. Independently these activities provided opportunities for students to reevaluate and revise their model, but in their entirety the activities did not scaffold modeling concepts.

Data Analysis

Warm-Up Answers

In order to group students heterogeneously I created a series of questions that students answered as a daily warm-up. Warm-ups were then collected, and nonparticipants' answer sheets were removed. That evening I read the answers to the warm-up questions and typed them verbatim into a chart (Appendix E). Key words or phrases from each answer were noted. I called these key words a code. Codes that were

similar were then grouped into larger ideas or themes. The themes were used to identify which idea of modeling was most closely related to the student's understanding of modeling. Students were assigned a number 1-4. These ideas of modeling were based on Treagust et al's (2002) study. That study identified five main themes centered on students understanding of models: "scientific models a multiple representations (p. 363), "scientific models as exact replicas" (p. 363), "models are explanatory tools (p. 364), "how scientific models are used" (p. 365), and "the changing nature of scientific models" (p. 366). I condensed these five themes to the following four modeling ideas:

1. There can be more than one model.
2. Models look the same.
3. Models help explain.
4. Models can change.

Once each student was assigned a number, they were put into groups of four with as many varying ideas of modeling as possible. The numbers do not show an increased understanding in the complexity of modeling but are simply identifiers to aid in grouping. The grouping of students was also dependent on students' ability to work effectively together and the adequacy with which they could verbalize their thoughts.

Group A. Group A was composed of four students: David, Corey, Isabella, and Wendy. David was identified as a 2, Corey was identified as 2, Isabella was identified as a 1, and Wendy was identified as a 1. Table 3.1 contains a list of all warm-up answers for each participant.

Table 3.1
Warm-Up Answers for Each Participant

Question	*Corey*	*David*	*Isabella*	*Wendy*
What do you think a model is?	A replica of something.	I think a model is showing the structure of something using materials.	Something that tries something on.	A model is a replica of something or someone.
What do you think a model is as it pertains to science?	An exact replica of something.	I think a model is, as it pertains to science, showing the relationships between elements, organisms, etc.	Something that recreates or looks the same as something.	A model that pertains to science is something like the human body or cells or organisms.
Why do scientists use models?	To look at things they couldn't just pick up and look at like a cell.	Scientists use model to have a better understanding of something.	To help explain what going on in a demonstration.	Scientists use models to show people things like cells, DNA, organisms.
How do scientists use models?	They use them to study things that they can't get.	Scientists use models to show their findings and look at someone else's findings.	When presenting something.	How scientists use model is they teach with them or to get information.
If you were to hear someone say "the modeling process" what do you think that means?	A process of scientists looking at a model of something.	If I heard someone say "the modeling process" I would think that means a process an organism goes through.	I think It means to show something important.	When I hear someone say "the modeling process" I think of how people make models or the process.

David's answers from his warm-up questions used words and phrases such as "showing structure," "findings and relationships," and "understanding." He was classified as an explanatory 3 because his answers indicated an understanding that models can show and identify a variety of different factors and models can be used to better personal understanding and to communicate information with others. He appeared to understand that models can be used to explain.

Corey mentioned several times in her answers that models are replicas and that they are used to examine copies of the real thing. Corey also noted that models can be used "to study things that they can't get." The theme that emerged from her answers was that she viewed models as copies. She was identified as a 2 because she mentioned in almost every answer that models are replicas, and she used cells as an example of model and how they are used when you cannot see the real thing.

Isabella identified different purposes of the model, such as copying, explaining, presenting and showing. She was identified as a 1 because she appeared to understand that there can be a more than one type of model and these models have different purposes. She identified that some models can be used as an explanatory tool while others look like the object they represent. Isabella also mentioned that models can be used to present or to "show something important."

The final member of Group A was Wendy. She appeared to understand that there can be more than one type of model. In her warm-up she mentioned that models can be made and that they can be used for teaching or for gathering information. She also referenced that models are copies of something. Based on these answers, she was identified as a 1.

Group B. Group B was composed of four students: Liam, Penelope, Alexandra, and Evelynn. Liam was identified as a 1, Penelope was identified as a 2, Alexandra was identified as a 1, and Evelynn was identified as a 1. Group B originally had two 1 and two 2. Due to extenuating circumstances one participant had to be removed. Of the remaining two students who obtained permission, one was identified as a 1 and one was

identified as a 2. Alexandra was chosen to participate in the group because of her ability to verbalize her thoughts and her ability to work within a group based on my classroom observations. Table 3.2 contains a list of all warm-up answers for each participant.

Penelope was the only 2 in group B. She was classified as a 2 because in her answers she mentioned that models "show" and "look like," meaning that they are a copy. When connecting models to science she said that models "can explain, more like to show DNA structure." While she mentioned a model's explanatory purpose, she referenced DNA structure, which in conjunction with her other answers indicated her understanding to be that models look like the real thing.

Table 3.2
Warm-Up Answers for Each Participant

Question	*Alexandra*	*Evelynn*	*Liam*	*Penelope*
What do you think a model is?	A physical example of an item.	A display to show understanding.	A model is a thing that shows what a product is.	A model is a structure to show something/what it's going to be/normal shell.
What do you think a model is as it pertains to science?	It shows you a physical image of what they are working on.	It can show the organization of something.	A thing used to show close up pictures.	Because it can explain more like to show DNA structure.
Why do scientists use models?	To have another way of showing that they're right.	To maybe show how things go together.	So they can determine what something is.	To show how it can look like if really small.
How do scientists use models?	They use them as examples to show people how they're [sic] experiment works.	Construct them to present.	They use it by opening parts.	They look at info and peace [sic] it together make models to show what it is.
If you were to hear someone say "the modeling process" what do you think that means?	I would think to hear it being said in a lab, I think it means a process of a physical thing.	The process of making a model.	A process of thinking being used.	To basically model and how they build it…

Liam described models in a variety of different ways. He mentioned that models show, but he also mentioned “determining” and “a thinking” process. Based on his answers he was identified as a 1, because he expressed varying ideas about models from copies and identification. Even though he referenced models as copies he demonstrated an understanding that models show whole parts and pieces. He appeared to understand that models can be manipulated.

Evelynn used the word “show” multiple times, but she followed up her “show” with other jobs of a model, such as “understanding” and “organization.” She understood that models can be used to present something and show connections. She was labeled as a 1 because she indicated an understanding that all models are not the same and models can have different purposes.

The final member of Group B was Alexandra. She was labeled as a 1, because she referenced several different uses of models. Models can be “a physical example,” the answer to a question “of showing that they’re right,” or for demonstration purposes “to show people how they’re experiment works.”

Audio/Video Transcriptions

To understand the nature of student conversations as they worked through an application assessment a thematic analysis provided an effective means of understanding the qualitative data. Roulston (2010) described thematic analysis as a way to identify themes from the data. Thematic analysis is a way to generate themes by reading through transcription and coding the data. These codes are then used to organize the data into

themes. “These themes are supported by evidence from the data set in the form of excepts” (Roulston 2010, p. 150-151).

Once all video/audio data were collected I simply sat, watched, and listened. After the first exposure to the data I transcribed all videos using FTW Transcriber and the infinity foot pedal. At this time any identifying information was removed. FTW allowed me to slow down the video speed and to adjust background and foreground sound. Making identification of spoken words easier. FTW was compatible with the Infinity foot pedal and allowed me to reverse, stop, or advance the video depending what was needed. As I transcribed the audio/video I noted motions, noises, and documents and/or materials that students referenced. While listening and transcribing I began to notice some commonalities in the student’s speech. I kept a journal as I transcribed, jotting down any interesting student comments or observations about their conversations. The journal contained thoughts and ideas that I had during all phases of data analysis. After the initial transcription was complete, I then read the transcripts correcting any formatting errors and noting interesting statements and sections I should listen to again. From there I replayed the audio/video while following along with the transcript and corrected any errors or added additional unspoken information, such as handing off documents to another student. Depending on the number of speakers at one time I would slow the video down in order to correctly identify speakers and their words. After reviewing the transcript and audio together, I read the transcript again and began to open code any reoccurring statements or ideas. Codes were based on the content of the students’ spoken words or what students were doing, such as asking questions or ending conversations.

Ideas that were similar were flagged and underlined, each differing idea had a specific color flag and underline. I called these ideas my codes. My initial codes are identified in Table 3.3.

As I coded, I continued to keep my journal, noting interesting and noteworthy information. Line numbers were added in the journal as a quick reference to different statements within the transcript. Codes were modified as needed based on students' words as transcripts were reviewed. From these codes several large ideas emerged.

After initial coding was complete, transcripts were uploaded into Atlas.ti (2019; version 8.4.18.0). As I read through my transcripts again, I used my original codes that I first noted while reading and added additional codes as new information was noted. I created memos and made notes on sections containing noteworthy dialogue. Atlas.ti allowed me to further examine sections of text that had the same code, such as modeling or data. Being able to access multiple quotations with the same code helped to shed light on what students did as they completed their modeling. These codes helped to identify the content of their conversations to help me understand how their conversations played a role in modeling. The codes that I generated from the student's words helped identify the students' use of modeling, but with so many codes it was difficult to understand how these codes identified the substance of their conversations. I thus began to view their conversations as a story. I conducted a narrative analysis to show the interconnectedness between the codes and to be able to provide an interpretation of their conversations as they attempted the modeling task.

Table 3.3
Initial Codes

Initial Ideas		Larger Themes
Problem solving Organizing To do/planning ahead	Specific tasks Idea Assigning	**Planning**
Knowledge Correct actions Color/shapes correct	Right Accuracy	**Checking**
Looks like Making Show Arts and Crafts Hands on	Jellybeans Cups Paper as Plastic animals Project	**Modeling Talk**
What if Problem solving After school activities Other classwork	Conflict minimizing Reassuring Interactions with other groups	**Discussions/Negotiations**
Offering new and additional ideas Should	Could Instead Different Opinion	**Change in thinking**
Beans Cups Mathematical	Paper Chart Graph	**Data**
Arguing Insulting Exclusion	Messes Stress	**Struggle**
Pinterest Populations Amazon	Memes Shopping Biomes	**Computer Use**
Graham Crackers Earth's Crust	Lab with Beans	**Prior Experience**
How many should How many does	Ratios	**Connections**

In order to understand the substance of their conversations as they collaborated during the modeling process, I began to view the text as a narrative. Freeman (2017) described narrative thinking as a way to assemble plot lines to make sense of what is going on. "Narrative thinking is based on the belief that narrative structures or plots reflect a basic human dependence, which is to connect events, characters, circumstances, decisions and so in, in a way that proves meaning to that experience" (p. 33). Galman

(2016) described narrative analysis as a different way to view one's data, "not as a body of information to be coded but rather a story to understand" (p. 56). Viewing the text as a narrative allowed me to find and plot the story of their modeling process and to interpret what was happening during these sections of transcript. Identifying their narrative means that the data does not stay in its original format (Maxwell & Miller, 2008). Generating a story from the data "is generally done by identifying key relationships that tie the data together into a narrative or sequence and eliminating information that is not germane to these relationships" (p. 467).

To understand the narrative of how each model was created I reread my transcripts starting with group A. As I read, I explored sections of text and noted what was happening during each section. Sections were passages of transcript where students were focused on one aspect of modeling. Using student quotes and written observations I began to construct my narrative. My narrative appeared as a web of thoughts (Figure 3.3). I completed the same processes with the transcript for group B (Figure 3.4). From these narratives a progression of activities emerged. I then took these different activities and arranged them in the relative order that students worked through their modeling task. These diagrams provided a way for me to coherently answer my first research question: What is the substance of students' conversations as they collaborate during the modeling process?

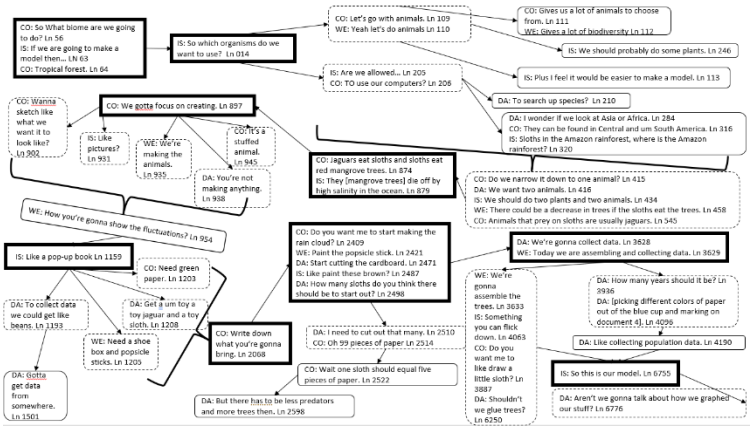


Figure 3.3 Group A narrative web.

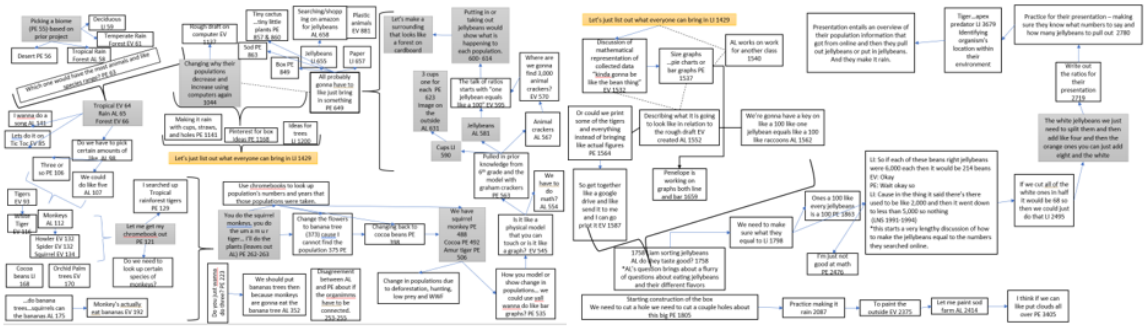


Figure 3.4 Group B narrative web.

Student Created Documents

To answer the second research question, I used documents students created in class along with their conversations to gain deeper insight about their use of modeling. I used student generated artifacts such as application assessment packets, rough drafts, drawings, digital resources, and three-dimensional renderings or photographs of three-dimensional renderings to gain deeper insight into students' use of modeling during the application assessment. In order to make sense of student documents I conducted an analysis on each of the documents received from both participating groups. Each document was examined, and commonalities were noted among the documents. A chart

was created for the documents which can be found in Appendix F. Documents were listed at the top, and the two groups were listed on the side. Boxes were filled in with observations from the various documents. The information from the chart was compared with the themes from the transcripts to identify commonalities and to see if students' spoken words coincided with with what students created or wrote.

Teacher Journal

Over the course of the school year I found that students clearly had preconceived notions about what constitutes a model. Because students had such limited knowledge of what constitutes a model, instructional activities throughout the school year incorporated a variety experiences centered on modeling. Prior to assessing these standards, students needed instruction on what constitutes a model and how to develop a model. As the teacher/researcher I am aware that what I said and did within my class could have had an impact on the outcome of my study. Since this study was focused on models, I kept a journal in class and documented times when models or modeling were mentioned within my class. My journal entries served as a source of comparison for student conversations to see if my instructions bled over into student comments and conversations. A list of activities that were mentioned prior in the curriculum are also included in my journal. An abbreviated format can be found in Appendix E.

All the items required for analysis were used in the triangulation of data. Juez (2009) said that if conclusions cannot be drawn from one source of data other sources should be explored. These other sources provided additional data for validity purposes. The data collected in various qualitative formats helped me to understand how students

navigated the modeling process and how the content of their conversations revealed their understanding of models and the modeling process. Appendix F identifies comparisons between the two different groups and the various data sources.

With these data sources I sought to gain a deeper understanding of how groups of students went about a modeling task and examined those conversations as they related to modeling. A variety of studies have explored students' views of models (Cheng & Lin, 2015; Krell et al., 2015; Lee et al., 2017), what students understand about models (Grosslight et al., 1991; Treagust et al., 2002) and how models assist in content understandings (Passmore & Stewart, 2002; Michalchik et al., 2008; Jong et al., 2015). While these studies provided quantitative and qualitative data and sometimes a mixture of both, none of the studies examined the students' spoken words and their underlying meanings. Answering my research questions required me to approach them through a qualitative research lens.

CHAPTER 4

RESULTS

Introduction

This chapter focuses on the content of students' conversations as they collaborated on their modeling task. Conversations were analyzed to gain insight as to what students' conversations centered on. From those conversations, sections solely dedicated to modeling were further examined to gain insight into students use of modeling. The first section uses narrative thinking to present the main components of each group's conversations, such as choosing their biome, model ideas, procuring materials, making their model, and presenting their model. The second part of this chapter focuses on sections of transcript that directly addressed the substance of their modeling talk to provide insight into their use of modeling. Prior knowledge, models as replicas, and the disconnect between the model and the data are some of the concepts that emerged from the student's conversations surrounding modeling.

Narrative Thinking

To answer the first research question regarding the substance of students' conversations as they collaborated during the modeling process, I describe what happened when students worked on their model. The transcripts from each group's conversations were used to construct a narrative about the group's modeling process. The

following two sections contain the narrative of each group's modeling process. I chose to incorporate the participants' own words to help tell their story.

On the first day of data collection prior to the work session students were given a paper copy of their application assessment. Application assessments are standards-based tasks that students completed, either individually or as a group. I reviewed the directions with students, reminded them they could use electronic devices, informed them of the supply bin at the front of the room, and then provided time for students to work (5 days plus 1 morning before school). For this application assessment students were asked to develop a model that could show the fluctuations of populations within their biome as resources and other populations fluctuate – meaning they needed to construct a model that they could collect mathematical data from. Occasionally, groups asked for clarifying information. To minimize my impact on what they were doing I attempted to answer as vaguely as possible and not impact the development of their model. Answering in this manner was not unusual; during all prior assessments I would answer similarly, but I was more aware of my answers during this process. Table 4.1 provides an example of how I (TE) minimally responded to an assessment question. Classroom procedural questions or comments made between participants and I were answered in a routine manner. The following table also contains an example of a conversation that did not pertain directly to their application assessment.

The beginning of each narrative was somewhat dictated by the directions on the application assessment. Students were to determine their biome and identify the populations within their biome that they wanted to focus on. Groups then had to

determine how they could show the fluctuations of their populations within their biome. The next sections focus on each group's separate narrative. This section on narrative thinking ends with comparisons between the two groups.

Table 4.1
Example Conversations

ASSESSMENT QUESTIONS	DA: there have to be, if there has to be ninety-nine with animals all together, how many sloths do you think we should start out with in the tray? TE: that's up for y'all to decide.
ROUTINE CLASSROOM CONVERSATIONS	EV: This monkey's eating a nutter butter. TE: It's eating a what? EV and AL: A nutter butter. TE: No, for real no.

Group A

Group A consisted of Corey (CO), David (DA), Isabella (IS), and Wendy (WE). During their modeling warm-up David showed a more developed understanding of models based on his answers. His understandings mirrored researchers' definitions of models, in that models can show connections and those connections can provide explanations (Baek & Schwarz, 2015; Bailer-Jones, 1999; Passmore & Stewart, 2002; Shen et al., 2014; Treagust et al., 2002). His understanding of models appeared throughout the creation of their model. Corey's answers indicated that she viewed models as appearing like the real object (Grosslight et al.,1991; Treagust et al., 2002). Her understanding of models as looking like the real thing showed up in her conversations with group members about what their box should look like. She rarely participated in what the group called the data.

Isabella's and Wendy's answers indicated they both understood that models have different purposes. They both also referenced models being copies of the real object. Their description of their model's appearance seemed to show that they referred to their model as a physical model (Gilbert, 2004; Harrison & Treagust, 2000; Ornek, 2008). The understanding of models, per their warm-up, was evident as they were able to work on both construction of their model and data collection. The following sections contain the narrative of how Group A developed their model. Group A's story followed a semilinear pattern with a split in the middle, as they could not determine how their model and their data intersected and later how they should have been merged. This group worked in a semilinear manner, meaning they did not reflect on their model and redo any parts that did not work. Their action was contrary to how Nelson and Davis (2012) and Lehrer and Schauble (2000) said modeling should be done. They described modeling as being nonlinear and that the first model created should not be the final model. Opportunities are needed to reevaluate and refine the model. While the students attempted to connect their model and their data, the result was data that was separated from their model. Once Group A completed their model, they did not show any action beyond using their model, they did not attempt to make any adjustments or refinements to their data or their model.

Determining Biome and Populations

Group A's application assessment began with the group identifying which biome they wanted to use. The group decided on the tropical rainforest "cause it's the most in depth" (Corey) and "it means a lot of organisms" (Isabella). The decision to create their model based on the tropical rainforest led into a discussion about which organisms

belonged in their model. There was a focus on animals because “it gives us a lot of animals to choose from” (Corey), “plus a lot of biodiversity” (Wendy), and “I feel like to would be a lot easier to make a model” (Isabella). The group spent time deciding on which animals to use in their model. Their discussion centered on organisms that would interact in nature and that were interesting. During these discussions the group began to use computers to research their animals. They used their computers strictly for acquisition of knowledge.

As they began to research animals, Isabella offered another suggestion. She proposed incorporating plants. She appeared to understand that animals cannot survive without plants. Isabella’s idea to add plants was dismissed, and they continued to determine which animals they wanted to use in relation to the animal’s habitat. They ultimately settled on the Amazon Rainforest because Wendy wanted to incorporate a macaw into their model, and through their research they identified a species of macaw that resides in the Amazon. They continued to use their computers to identify other organisms that live in the Amazon. Sloths, monkeys, and tigers were a few of the organisms that the group researched. Isabella, with the help of David, again implored the group that they needed to incorporate plants. David suggested, “So we find sloths and a type of tree, and so we put a sloth in a type of tree.” His idea went unheeded, and the discussion continued around two animals. The idea of using the sloth and the tree was temporally forgotten until Isabella suggested using “two plants and two animals…that one plant and that one animal interact, and then that one plant and that one animal interact.” A decision made by Corey to use a three toed sloth started a discussion that

showed the interconnectedness of organisms within their environment. The ensuing conversation indicated that students in Group A understood that sloths consume trees and jaguars consume sloths. They also appeared to understand that a change in tree populations could cause a change in sloth populations.

Each member spent time trying to determine what would cause a decrease or an increase in the red mangrove tree population. Isabella found a website that discussed how salinity affects the health of the trees. With the newly learned information about salinity, the group came to a final decision on what went in their model. To view snapshots of student conversations as it pertains to determining their biome and their population see Table 4.2. Their desire to use only organisms that would interact within their environment showed that Group A was attempting to make sure they were correct. The desire to have a correct model was similar to that of Schwarz et al. (2009) findings that students viewed models as correct answers. With their organisms finally decided they start to brainstorm ideas for their model. The next section shows that a division began to emerge in the group's understanding of what constitutes a model.

Table 4.2
Excerpts of Discussions About Determining Biome and Populations

TOPIC	EXAMPLE CONVERSATIONS
NEW IDEAS	Is: We don't wanna do any plants? We: No, we are doing animals. Is: We should probably do some plants.
FINIAL DECISION OF ORGANISMS IN BIOME	Co: It says [reading from computer] "Animals that prey on sloths are usually jaguars." We: Okay, let's put a jaguar instead and he goes, "rawr!" [makes cat noise with clawing hands] Co: Jaguars eat sloths, and sloths eat red mangrove trees, Is: And the mangrove trees, Co: Die. Da: They just die because of saltwater [overtalking]. Is: No, they die, they die off by high salinity in the ocean.

Model Ideas

The movement toward model creation was started by Corey when she said, “We gotta’ focus on creating,” suggesting that all models are something physically created (Harrison & Treagust, 2000; Gilbert, 2004; Ornek, 2008). Corey suggested sketching out what they wanted to do, and then she drew a three-dimensional box on a sheet of notebook paper (Figure 4.1) and discussed using a box for their model. At this point a division appeared within the group. Corey, Wendy, and Isabella all held views that their model should look like their biome.

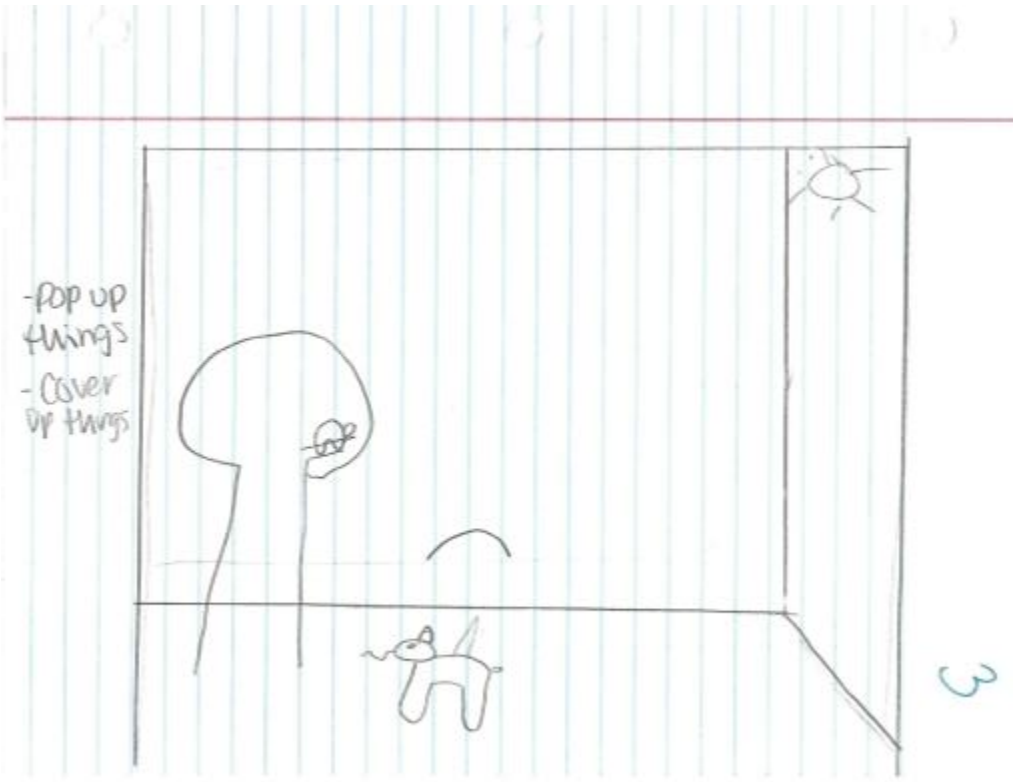


Figure 4.1 Corey's rough draft.

David attempted to redirect the group by saying, “you’re not making anything,” went unheeded, and the group decided on using a box and making it look like their biome. Discussion ensued of what would be the ground, where the sun might go, and the need for a rain cloud since it was a rainforest. Additional ideas were offered, such as using stuffed animals, plastic animals, and pictures. Isabella even offered the idea of the model being “like a doll set, like, you could drag the jaguar over to the sloth.” In all their discussions David’s idea of what the model should be was overlooked. The rest of the group was under the impression that developing a model involved making something that looked like the real object; in this instance, their model should look like their biome (Grosslight et al., 1991; Treagust et al., 2002).

When Lee et al. (2015) studied collaborative modeling, they found that individual learning influenced the group – but not with Group A. David attempted to explain to the group several times his view of models, but he was unable to provide enough evidence or information to convince his group that they did not need to construct a similar object to the real thing. Wendy likened their future model to that of a picture book with moveable parts. Again, David attempted to help the group understand what he thought they should be doing. David reminded everyone of class activity that modeled population sampling. Table 4.3 contains the full discussion. During the activity students had a selection of beans in a bag. Extra beans were in a cup, and depending on what was happening within the environment, beans were added or removed from the bag. After each addition or subtraction within the bag, students picked a bean out, recorded the color, and replaced

the bean in the bag. This activity was loosely modeled on how researchers observe different populations within an ecosystem in order to estimate the population size.

Table 4.3
Model Ideas

TOPIC	EXAMPLE CONVERSATION
DIVISION OVER MODEL	Is: how are we gonna do the model? Are we doing like pictures? Co: No, we're, Is: We're making, We: We're making the animals. Co: I need a ruler We: Making a giant sloth. It's gonna be like thi. We should use it out of pipe cleaners. Da: You're not making anything. We: Yeah, well whatever. Da: I don't think that's what we have to do. Is: What do you think we have to do? Co: But I thought we were gonna actually make something.
HOW TO SHOW CHANGES IN FLUCTUATIONS	Is: I'm just confused at how, we have to really think about how we are going to show that [overtalking], Is: In a model, We: 'Cause, like, what I was thinking we could do is we could like make them so we could, like, fold them over. So that means, Is: Like a popup book [overtalking], We: Yes, that's what I was thinking, a, like you could, could take a popsicle stick with the jaguar (Rawr!) eats the sloth. Does that make sense? Co: Yeah, like, what we could do is we could cut like a little shape, like this—and then you could put the sloth on the floor, and then you could stick a popsicle stick through this and poke it through the hole and so like. whenever we move it makes it look like it jumping up through that…
USING PRIOR KNOWLEDGE FROM LAB	Da: The lab with beans. Is: With the beans. Da: It needs to be like that. Is: Don't worry, David, we'll, we'll get it.

Wendy, noticing David's apparent concern over their ideas, told him, "We're not going to put just put a bunch of little stuffed animals in a box, okay?" While they did not end up using stuffed animals in their box, their plan to show fluctuations within their biome centered on the ability to move small plastic animals within their box (Grosslight et al., 1991). Isabella, Wendy, and Corey finally decided that their model would be.

Isabella stated, “Like a pop-up book.” Wendy knowing they were to make a model, stated that they were making “a model of a children’s book” that would allow them to show changes in populations (see Table 4.3 for discussion). David again offered a suggestion to collect data by acquisition of “beans and stuff,” drawing again on the population sampling lab that used beans to represent the different populations within a given space (see Table 4.3 for discussion). David was able to devise a model using prior knowledge that was abstract compared to the rest of his group. David’s ability to conceptualize a different version of a model mirrored Schwarz et al.’s (2009) findings that some students could create a model that was different than the original concept.

Planning. As the group determined what materials they needed for their model, Corey, Isabella, and Wendy focused on bringing in materials that look like items within their biome. Even though David appeared to have a more sophisticated view of models, he still offered to bring in objects that would create an environment that looks like a rain forest, such as “a toy jaguar and a toy sloth.” These discussions mirror findings from studies done by Grosslight et al. (1991) and Treagust et al. (2002). They found that students viewed models as tiny reproductions of much larger objects. Their conversations of what materials to bring in also brought about sporadic conversations of planning.

While the discussion mainly centered on what they needed for their model and how they were going to make the animals and plants pop-up, David looked for suggestions as to how to collect the data for their model. He asked, “How are we gonna show beans or,” and then again, “Are we gonna put beans or, like, what are we gonna show to?” Each time he mentioned beans both Corey and Isabella responded with an

inquisitive “Beans?” Isabella then tried to clarify for David how they are planning on showing the population fluctuations “to show the change in population we are flipping them up, and then for an increase and then for a decrease we flip it down.” She meant that they would move trees in an upright position to show an increase in population and lay them down to show a decrease in populations. They wanted to make parts of their model move to show changes in populations. The suggestion of making something three dimensional aligns with findings from Lee et al. (2017) and Grosslight et al. (1991), as they both found that students preferred models that were more realistic in their appearance in three-dimensional space. Isabella’s suggestion for how to model changes in population by moving plants and animals started a discussion that pitted David against Corey, Isabella, and Wendy. See Table 4.4 for conversations that show a gradual shift to the creation of the model and the data.

Later, David again suggested the population sampling lab and attempted to get the rest of the group on the same page by saying, “That’s what we’ve kinda’ got to do with this.” Isabella’s prior dismissal of David’s suggestion about using beans and the idea of using a prior lab is more clearly understood when she responded, “That was a model?” Isabella’s conceptual understanding of models mirrored findings from Grosslight et al. (1991) and Treagust et al. (2002) that models should look like the real thing. Isabella appeared to wrestle with understanding that models do not have to look like what they represent, even though throughout the school year she had been exposed to a variety of models that did not appear like the real thing. As Isabella attempted to merge her naïve understanding of modeling with what David has recommended, she suggested, “I think

the pop-ups is okay, but like, also we need to add something." David offered additional ideas to use in the place of the beans, such as "extra gum" or "gum wrappers." These suggestions were met with disdain from other members. Corey asked, "How do gum wrappers look like sloths?" Unable to come to a consensus within the group about what the model should look like and how the data fit in, they began to reference the data and the model as two separate entities.

Table 4.4
Example Conversations Showing a Gradual Shift to the Creation of the Model and Data

TOPIC	EXAMPLE CONVERSATIONS
PLANNING	Co: Yeah, because if we want the jaguar to be, like, against this, but you'd pull the popsicle stick all the way through the box to where the jaguar is on the box wall so we would be able to move it We: Yeah, we're gonna have to be, but like make it so you can, like, so you can't see it. So we're gonna have to make sure the width of the hole is only big enough for, like, you really can't see it but big enough for you to show, 'cause it has to be able to, like, kinda' move around the thing instead of taking it out.
DISAGREEMENT OF HOW TO SHOW POPULATION CHANGE	Da: No, I know, but, umm, we still gotta show an increase. We: I know. That's what we're gonna show, right? Does that make sense [overtalking]? Da: No. We gotta, we've gotta take data. We've gotta, like, I don't know, We've gotta get data from somewhere. We gotta sh— try to show populations Is: Yeah, you can just count them [overtalking].
DIVISION OF DATA AND MODEL	Is: How are we gonna show for the trees, we are using pop ups and and paper? We: —and paper and images Is: —and for the data. Da: Trees would be green paper, sloths will be brown, and jaguars will be black paper.

Oliveira and Sadler (2008) found that students need to challenge each other for greater detail when explaining concepts. Isabella, Corey, and Wendy did not challenge David's views. They either ignored his comments or asked questions that did not foster knowledge growth or require explanations. Viewing the model and the data as two

different entities mirrored a study done by Komis et al. (2007) that found when working with plants students could not make the connection between growth and photosynthesis. Similarly, Group A struggled to make the connection that data showing population change should be coming from their model.

In all their discussions on what they needed to bring in and examining materials that were available in the classroom, David once again attempted to align the group with his thinking by saying, “Isn’t all we need is construction paper” and cups, to which Isabella responded, “Why do we need cups?” David’s response mirrored our class’s use of cups throughout the school year. He said he needed cups “to put everything together in to take it out.” David’s alternative understanding of a model solidified his role as the collector and interpreter of data. Isabella acknowledged David’s connection to the data by saying, “We’re probably not helping you, but we’re just like ‘la la la,’ and you’re like, ‘One, two, three, four.’”

Occasionally other group members would attempt to cross their cognitive divide and try to reconcile their understanding of a model with David’s understanding of their model. Their attempt at reconciliation had them attempt to merge the two ideas into one when explaining what they were trying to do. This strategy was evident in an interaction between David and Wendy. He said, “It’s gonna be in the cup, the squares we cut out, and we’re gonna get a cup. I mean, get a piece of construction paper out of the cup, and then when we pull that out, we’re gonna do like the tally.” As David explained the data collection process, Wendy attempted to link the data collection to the model by saying, “And then you pop up like whatever the tree is.”

Even though there was an attempt to merge the data and the model, at this point their narrative became divided: data versus the model. Isabella, Corey, and Wendy focused on building their model and offered occasional help to David and his data. David willingly helped with what he called “arts and crafts” but took on the job of collecting and interpreting data. While the next two sections about building the model and the data are listed in a linear manner, they did not occur that way. They occurred simultaneously, with members going back and forth between the data and the model. Sometimes the back and forth brought confusion and strife as conversations overlapped and members became confused.

Building the Model

As they began to build their model the group spent a significant amount of time making sure that the parts of their model were physically accurate (Grosslight et al., 1991; Treagust et al., 2002). As they worked on their model, they tried to make sure that it was aesthetically pleasing (Figure 4.2). Corey started off with creating a rain cloud from cotton balls, string, and popsicle sticks that formed a handle. She was very meticulous in making sure that it looked like the real thing. See Table 4.5 for the conversation surrounding the construction of various parts of their model. As Wendy began to paint popsicle sticks to resemble tree trunks, she wanted to make sure that the trees were physically accurate, so she asked “do you know what a tree like that tree looks like?” Ironically, David was unable to procure a plastic sloth and brought in a plastic gorilla, and much care was put in to making sure it looked like a sloth and not a gorilla. Isabella told the group that they needed to paint the gorilla “to make it look like a real

sloth.” In order to make sure that the parts of their model were accurate, time was spent mixing paint, choosing paint brushes for specific jobs, and attempting various paint application methods.

Figure 4.2 Completed model.

As the group worked, the body of water posed a problem for them. They wanted to include water because the red mangrove trees thrive along shorelines. When they created their water source, Isabelle cut out a shape that she referred to it as “our pond.” This action caused a slight disagreement as to how they were going to reconcile their pond into their model of a tropical rainforest near a body of saltwater. Their solution was to create a new version of a body of water that fit their model. Wendy called it “a saltwater tide pool stream” (Table 4.5 for their conversation).

Table 4.5
Example Conversations About Building the Model

TOPIC	EXAMPLE CONVERSATIONS
CLOUD APPEARANCE	Co: I'm gonna glue these together [talking about cotton balls]. Do you have any gray markers? Is: Yeah, I have, like, every, every color. Here you go. Co: Thank you. I need to make it look like a rain cloud. Is: [laughs] Why are we coloring it, that looks really grey, for? Co: Because it's a rain cloud.
TREE APPEARANCE	Co: No, you just, you dip, like, you dip it in all three of them and you get just, like, a little bit of each of them. We: Oh, that looks cool like this. Co: Yeah [holds up her treetop]. Is: Yeah, that looks good.
SLOTH APPEARANCE	Co: Just make it look darker than it is. Is: Yeah, that, this is, this is the sloth brown. If you want you could mix it with like black or something. We: Or like, you should mix [overtalking] – Co: Wait [overtalking] – We: those two together [overtalking], Co: No, you should paint the whole sloth that light color and then make the fur streaks with the darker one.
BODY OF WATER	Is: Guys, this is our pond. Da: Aren't we supposed to have an ocean Is: What? We: What? Da: 'Cause remember, it said that mangrove trees – We: Yeah, the salinity [overtalking] – Da: They filter out saltwater. Ponds aren't saltwater. They're freshwater [overtalking]. Co: This could be a salt, this could be a pool [overtalking] – Is: No, it's a tide pool [overtalking]. We: Yes, it's a saltwater tide pool stream. Got it.
SLOTH MOVEMENT	Co: So we'll have it [sloth] like this drinking the water, and the stick – Is: And then when the jaguar comes over and eats, it lift up, and it'll be dead. Co: It'll lift up to where you can't see it .

As they decided how the various parts of their model were going to look, they also brainstormed different ways to achieve the desired movement within their model. The movement within the box was to show the fluctuations of populations within their biome and to make it "interactive" (Wendy). They collectively worked to determine how to make their organisms move like their popup book idea. There was a struggle in making

their organisms move, but they determined that by using string and popsicle sticks, their organisms could move. Rain cloud movement was fairly simple, and Corey suggested,

> We could make like a handle like this [makes a T shape with two popsicle sticks] and then glue it to the top of the rain cloud, so we could drip the rain cloud down and make it look like it's raining and then pull it back up whenever we're done and just put it off to the side.

Later Corey suggested trees could be moved "with string." Moving trees with string ended up being more difficult than they had originally thought, so in the end there was only one tree that somewhat moved with string (Figure 4.2 for the tree that is down). Isabella and Corey suggested gluing the trees, but Wendy was concerned with "how are we going to move them?" As a compromise small holes were put into the base, and some trees were stuck in the holes so that when the rain cloud came along the trees could grow by standing them up and placing them in the premade holes (Figure 4.2 for standing trees). In addition to the moveable trees, they wanted to have a moveable sloth and jaguar. Corey suggested having the sloth "drinking the water," and Isabella added to that thought by having the jaguar eating the sloth. The sloth disappeared by being pulled up by a string. See Table 4.5 for an example conversation about sloth movement.

As they planned out their model, they were mindful of what they needed to do and how a mistake could ruin their box. They discussed at length what they were going to do before they acted, specifically when it came to things that could not be undone, so that items in their box would not be viewed as incorrect or wrong (Schwarz et al., 2009). Before they cut a hole in the back of the box Wendy suggested, "Let's first mark where

we want to put the … I need to borrow a marker so we need to mark where how big and where we want to cut on the back." Wendy was not the only one concerned with making sure they did not make a mistake. Isabella described cutting the holes in the box for the jaguar by saying, "[You] gotta make sure, like, see, this is difficult because when you cut it. You can't uncut it and, like, if it's not perfect, the jaguar might not be able to eat it."

During construction the group chose to not use the plastic animals for fear of irreparably damaging something. They used other available items to stand in for the real parts of their model; for example, a plain popsicle stick was used for the jaguar. Once they were sure nothing would be ruined, Isabella suggested, "OK, now let's try it with the real thing [picks up popsicle stick with the jaguar on the end]." As they worked on their model, David would go back and forth between working on the model and working on the data.

The Data

David started the process of data acquisition by attempting to determine how many of each organism there should be in the original population. This was similar to the population sampling activity done prior in the year. In the population sampling activity, a starting population was given to represent the population of organisms that were in the wild the first year of the sampling. Similarly, David asked, "How many sloths do you think there should be to start out?… 'Cause there needs to be an equal number of thirty-three," which he then changed to "ninety-nine." The suggested "ninety-nine" brought panicked responses from the group. Wendy said, "Not ninety. We don't need to put a hundred." David replied, "I need to cut out that many." Corey attempted to clarify the

conversation by saying, “Ninety-nine pieces of paper.” These pieces of paper were a representation the different organisms within their biome. The use of pieces of paper to help collect their data could be viewed as an analogical model. They took something that could be considered complex, the various populations, and made them easily accessible by using colors of paper to represent the variety of organisms (Gilbert et al., 1998). After not getting a definitive answer, David again asked how many of the different organisms should they start off within each population. He told Isabella, “It says they’re three organisms. We need around ninety-nine.” Isabella then responded, “So what’s ninety-nine divided by three?” David and Isabella both responded, “thirty-three.” Isabella then said that there should be “around thirty-three of each of them.” Isabella appeared to realize that an equal number of organisms within a population might be detrimental to the environment. She said, “Maybe, like, we should have less.” David agreed and said, “There has to be less predators and more trees.” Isabella added to David’s thought by suggesting, “Like, less jaguars than sloths and less sloths than trees.”

A similar conversation occurred when deciding how many trees and sloths to add to their population so that it would be compatible with what would be found in nature. Over time they focused on making sure the numbers made sense and that their total population equaled 99. The ensuing conversation had all members talking over each other about different numbers of organisms. Corey asked, “How many sloths do we have?” David answered, “Uh thirty-nine,” to which Corey replied, “Do nine.” Corey was responding to a prior question about jaguars. Then Wendy suggested, “How about you do ten,” to which Isabella responded, “How many trees?” Their overlapping conversations

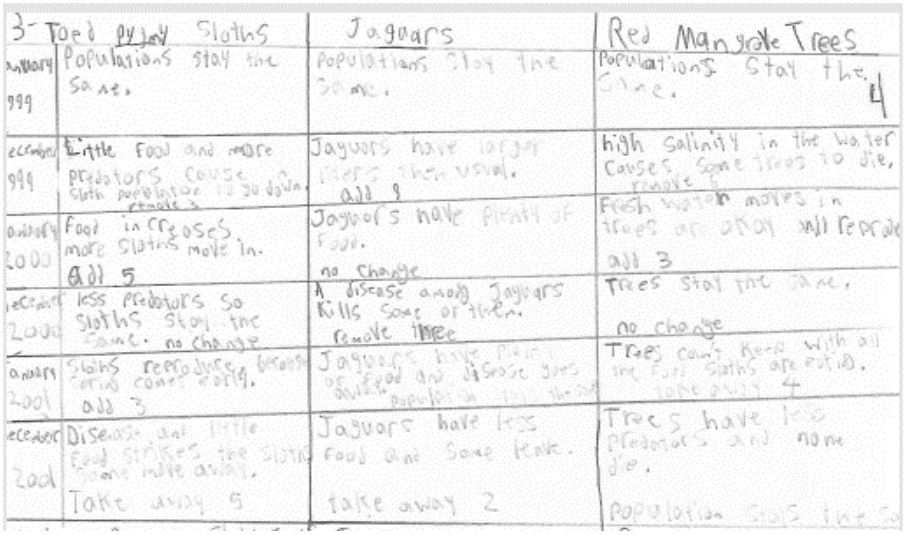
made it difficult for them to come to a unanimous conclusion. At times they were all talking but not about the same thing.

As the group tried to determine how many organisms were needed in their original population, they attempted to reconcile how the items in their model were related to the pieces of paper within the cup (Figure 4.3). Isabella said, “One sloth should equal five pieces of paper,” to which Corey responded, “If you just put nine, one sloth could equal nine.” As the discussion continued, Wendy referenced the population sampling lab by suggesting, “But if they said, like, take out sixteen beans, that would be like—” The conversation continued until Isabella abruptly told David to “just start cutting.” Many of their comments that abruptly ended conversations or their ignoring of each other’s comments could be considered negative interactions. These negative interactions can impede understanding within the group (Oliveira & Sadler, 2008)

Figure 4.3 Data collection cup.

As the group worked on their model, occasionally the conversation turned back to the data. Questions about the data were directed at David and typically described how the

process was going. When Isabella asked, “David how’s the data part going?” David responded by picking up the plastic cup and saying, “I got it.” David occasionally checked with the group to make sure that they agreed with what he was doing. He would ask, “Are we into agreement as to how we are doing?” Isabella and Wendy both offered reassurances to David as he continued to work on the data: “David, yeah, you’re doing a great job” (Isabella). “Probably doing the best job out of all of us…. You do what you think is best” (Wendy). These assurances made it appear as though the group had identified the data as belonging solely to David. As David began creating the story that described what was happening in the environment at various years, he often asked the group for assistance in developing the instructions for the story behind the data (Figure 4.4). He wanted to know how many years the data should be collected and what happened to the organisms during each of those year spans. He began by asking, “How many years should it be?” Wendy responded with, “four, five.” David asked the group again how many years: “Three or four years, guys?” Corey and Isabella both agreed “three” years while Wendy suggested, “How about four?” Wendy, still not in agreement suggested, “How about three and a half?” She was vetoed again, so she changed the topic of their conversation to what happened in the environment during that year. Utterances like Wendy’s appeared as nonproductive, since there was no explanation as to why she suggested different years. These unproductive interactions limited their learning, in that group members did not seek out explanations for her answers (Oliveira & Sadler, 2008).



3- Toad [illegible] Sloths	Jaguars	Red Mangrove Trees
January 999 Populations stay the same.	Populations stay the same.	Populations stay the same. 4
December 999 Little food and more predators cause Sloth population to go down.	Jaguars have larger litters than usual. add 9	high salinity in the water causes some trees to die, remove 3
January 2000 Food increases more Sloths move in. add 5	Jaguars have plenty of food. no change	Fresh water moves in trees are okay all regrow add 3
December 2000 less predators so Sloths stay the same. no change	A disease among Jaguars kills some of them. remove three	Trees stay the same. no change
January 2001 Sloths reproduce, bring some early. add 3	Jaguars have plenty of food and disease goes [illegible]	Trees can't keep with all the Fast Sloths are eating. take away 4
December 2001 Disease and little food strikes the Sloths some move away. Take away 5	Jaguars have less food and some leave. take away 2	Trees have less predators and none die. Population stays the [illegible]

Figure 4.4 Story and years for model.

After the group decided what was going to happen during that first year David would pick a piece of cut paper out of the plastic cup (Figure 4.3). He would then put a tally mark on his paper in the appropriate column (Figure 4.5). He would often elicit help from other members to pick papers. Sometimes the members gave the task to other members so they could take jobs that they found more desirable, such as painting, and sometimes they would help. As members assisted David with data collection by pulling papers out of a cup, he recorded that number a sheet of paper (Figure 4.5). After the helper picked 33 pieces of paper out of the cup, David would count the tally marks for each color, then multiple each of those numbers by three. He considered this action to be "like collecting the population." Their process of data collection was not without some unforeseen difficulties.

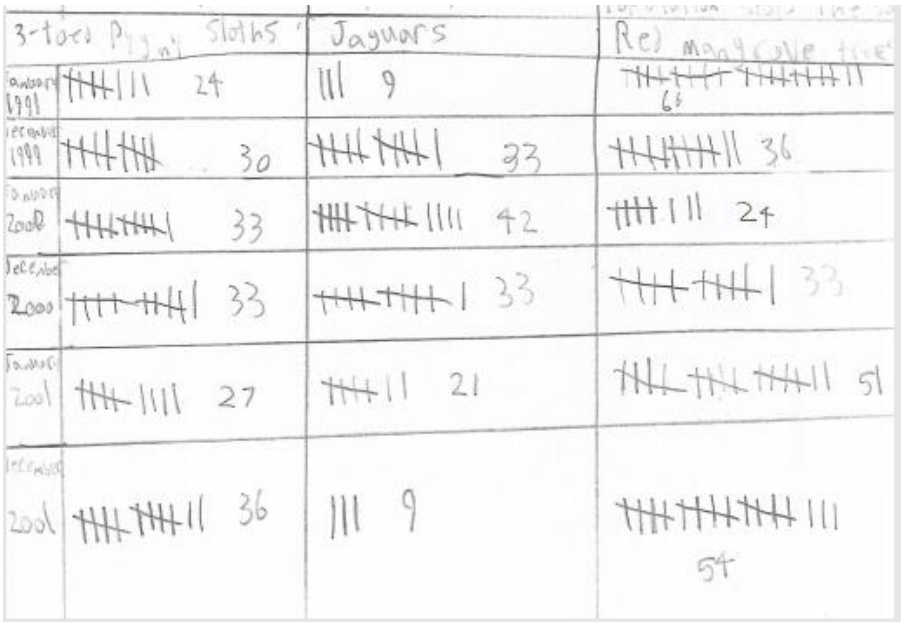


Figure 4.5 Data collection table.

Since there were multiple overlapping conversations within the group, sometimes adequate care was not given to the data, especially compared to that of the model. David would request a certain number to be added or removed from the cup, but other members would add or subtract different pieces of paper. When members realized that no one knew how many papers had been put in or taken out of the cup, they continued as though the data were correct. Table 4.6 shows an example of the confusion that was created during data collection. When this type of confusion occurred, the group did not take the time to settle the uncertainty. The issues were glossed over, and they appeared to act as though accurate data collection were unimportant.

Table 4.6
Example Conversations Indicating Data Confusion

DAVID	How many are in the cup? [picks up the cup]
WENDY	We already added three.
DAVID	I needed to add brown paper.
WENDY	Wait, we already added two. Did we already add three browns?
ISABELLA	Yeah, we already the tree browns.
DAVID	No, we have three. I'm adding five.
ISABELLA	But we already added the three for both, so you only need to add two.
WENDY	[Takes three out] Okay [takes cup], I'll take three out.
DAVID	Oh, just two, we only needed six.
ISABELLA	No, you take three out 'cause we added three, so all you needed to do was to take two.
WENDY	We added three, but we only need to add five, so we take three out, okay?
DAVID	Don't take two out, 'cause we put three back in and then we need to add five back.
ISABELLA	No, but then you, you added five, right? What did you do?
WENDY	[laughing]
ISABELLA	Wendy –
WENDY	I –
DAVID	We only need to add one more.
WENDY	We added three, but, and then you added two more, so that's five.
DAVID	No I didn't.
WENDY	And we need to have six.
DAVID	We have to do what it says.
WENDY	Do we? Okay, I think this is fine. Let's just go with what we have.
ISABELLA	Kay, it's fine.
DAVID	Yeah, that's fine.

Upon completion of their data collection David discussed with the group the best way to present the data that were collected. He asked them, "Should we do a graph or should we just … leave it like this? [as he held up Figure 4.5]." A discussion ensued as to how to graph the data, and David decided on a line graph. There appeared to be an understanding that the graph (Figure 4.6) had a purpose in displaying their data when Wendy said, "Cause then it will also show our fluctuations... our fluctuations in our environment." They did not consider their graph to be a type of model, but based on their description of how it could show connections between organisms, it could be considered a symbolic or mathematical model (Gilbert, 2004; Harrison & Treagust, 2000) because

their model used a “convention of math” (Gilbert et al., 1998, p. 92). Glancing at Figure 4.5 does not provide enough information for readers to understand what it means. This is typical of models that incorporate symbols or involve mathematical representations. They typically require some type of interpretation for readers to understand the context of the graph (Treagust, 2000).

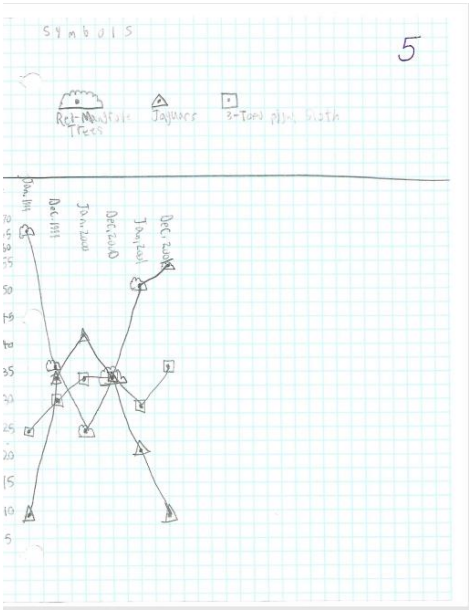


Figure 4.6 Graph of data.

Attempting to Connect

As the group constructed their model and collected data, they often tried to make connections between their model and data. While they did not appear to understand that the data needed to have been collected from their model, they seemed to think that they needed to connect the two.

Wendy frequently started discussions about how to mathematically link what was in their box to what was going on within the cup. She did this by attempting to create

ratios between the model and data. She would ask, “How many counts for one?” and when she did not get an answer she asked again, “Wait, how many count for one?” When she still received no response, she became more specific: “How many trees represent, like, one tree represent how many trees?” Isabella eventually responded “three.” Wendy responded with, “and then the sloth and how many sloths represent?” Table 4.7 provides two examples of how the group attempted to connect the data and their model. This concept of connecting their data to their model while their model was being constructed showed that they lack an understanding of where data came from.

Presenting Their Model

Groups were asked to present their models to small groups of students in approximately 5 minutes or less. This request caused groups to focus only on presenting what they perceived as important. They made sure each of their organisms was in the proper spot and that all animals were ready to be moved (Figures 4.7 and 4.8). They also wanted to test all the movable parts within their model. After they ensured that everything worked, their first audience arrived for their presentation. The section of transcript in Table 4.8 is from their first presentation. They demonstrated how each part moved when there was a change in the population amount. Discussion of their data and graph was left to the end and was only addressed after David asked if they were going to mention the graph. Each of the subsequent presentations were similar except for the presentation of data.

Table 4.7
Example Conversations of Group A Attempting to Connect the Data and Their Model

TOPIC	EXAMPLE CONVERSATIONS
EXAMPLE 1	We: How many trees represent, like, one tree represents how many trees? Is: Three [talking to Corey]. We: One tree represents three trees [overtalking]. Is: Yeah, so that's like twenty-four. We: And then the sloth, and how many sloths represent?
EXAMPLE 2	We: Okay, so one panther accounts for how many panthers, except for that one? Is: Five panthers in the model or going to be in the model. We: It, but how many, one counts for how many panthers, like one panther counts for how many, 'cause like, one sloth counts for how many sloths? Is: Why? We: Because you're not, just 'cause if you're just gonna have one sloth, there weren't be, that there would be more in the population. Is: Oh, um, we, yeah. We: And one tree counts for three trees. Is: Yeah. We: One sloth can counts for how many sloths, probably like three? Is: Ummm. We: Or four? Is: So three. S that would be like – We: One would count for three sloths. Is: And then twenty, oh, and twenty-four trees, cause three times eight, we have eight tr— We: Four, yeah, four. Is: Four times eight is thirty-two, and then nine, three sloths, wait, and then twenty-seven, thirty-two, and then the panthers need to be kinda small. We only have five of those, so like—

Figure 4.7 Preparing for presentation.

Figure 4.8 Test of movable parts.

Table 4.8
Transcript From Group A's Presentation of Their Model

ISABELLA	So this is our model.
WENDY	It is the tropical rain forest, if you can't tell. So how we showed the fluctuations in our biome is our little hands-on interactions book or box— Okay, here we go, okay so—
ISABELLA	So let's say the sloth, this is a sloth by the way. All of these are sloths [points to gorilla/sloth and paper sloths]. Let's say the sloths decrease because the jaguar eats it. Okay, so now there's a dead sloth right there. [Wendy pulled up the gorilla/sloth] Okay, yeah, your turn to talk now with the rain cloud [talking to Corey].
COREY	Oh, so the trees will increase because there is a bunch of precipitation in the area [moves rain cloud over box and stands up a tree].
ISABELLA	Yeah.
WENDY	And then because of all the precipitation in the area since the sloth's population grows, so does the jaguar's population as well [Folds down bush showing a jaguar. Isabella folds down the other bush showing the other jaguar.], so then the jaguar continues to eat the beautiful sloths.
ISABELLA	And because he eats the sloths, the sloths go down [takes down a tree with two sloths in it. Wendy takes down another tree.].
WENDY	And then because of the sloths not eating the trees anymore, the trees grow and the sloth's population grows as well, as you can see [setting trees back up], and then because this happens, the jaguars populations grow as well. Thank you.
ISABELLA	Thank you.
DAVID	Aren't we gonna talk about how we graphed our stuff?
WENDY	Oh, okay.
ISABELLA	Okay, you go and do—
COREY	Do we have to?
WENDY	Wait, we're not done.
ISABELLA	We have the graph.
WENDY	So this is how our, okay, hold on. We need both of these, okay. So how we got our information or data is I'll just read the paper. Well, what we did is we kinda, how we did with the beans and stuff, so we used paper.
ISABELLA	Three colors.
WENDY	Okay.
ISABELLA	Green is the trees, brown is the sloths, and black is the panthers, er I mean, jaguars.
Wendy	And so we did it in years, so it goes from 1999 all the way to 2001, and we did the data as well, and like, we showed, like, add five remove three, or things like that, and then we graphed it, and so what we did is, this is the jaguars, this is the panthers—
DAVID	The populations go up and down as years go by.
ISABELLA	The sloth is reborn [moving gorilla/sloth].
WENDY	The sloth is and then dead again [moving jaguar on a stick].
ISABELLA	Dead again.
WENDY	And then you go, yeah, and so it's pretty much the same process each time, so sloths eat trees. Trees start to die. Sloths die. Panthers die. All the things like that, you know, it's a really fun conception.

As the group presented a second and third time, their presentations were almost identical except for their explanation of data. The next two times they presented they

further minimized the discussion of the graph and data. Table 4.9 contains the second presentation of their data collection. The lack of attention shown during the presentation of their data collection and how their data and model were viewed as two separate entities, appeared to show a lack of understanding for how important data collection can be in science. This lack of understanding is similar to findings in a study done by Treagust et al. (2002). When looking at changes in models due to changes in science they found that students struggled to make connections between the changes in the model and the development and changes in scientific ideas. This apparent lack of connection was also seen in Group A as they lacked an understanding of the importance of data in science and how that data can influence future scientific endeavors.

Table 4.9
Transcript From Data Portion of Group A's Second Presentation

WENDY	Okay, so then, now we're going to explain to you our graph.
COREY	Okay, go.
WENDY	Okay, so how we did this is, we pretty much did it like the beans. We have three different, three, hold on.
ISABELLA	Three different colors of paper.
WENDY	Colors. Broth, sloth, um, black for jaguar and green for tree and the, you like picked them, and we did all that, but what we did before we did all that is, we put right there what we're gonna do, , take three out, add three, and we multiplied them times
DAVID	Three.
WENDY	Three. And we did, and we did this, um, thirty-three times on each, and then we calculated it, and then we, for our graph we, that's like, it's kind of its own thing. We kinda interlaped [sic] with the other to be, you know, creative, um, and –
DAVID	It shows how the populations go up and down
WENDY	Yeah so
DAVID	Over a specific time

To summarize Group A, these students worked independently and collaboratively to build a model that showed fluctuations of organisms within an environment and developed a way to collect data, albeit not from what the majority of the group

considered a model. They began by determining their biome and which organisms they wanted to include. Organisms were chosen based on where they lived and if they interacted with any biotic or abiotic factors within their biome. Once they had their biome and population, there were various suggestions as to how to make their model. Determining how to construct their model showed the first sign of division within the group. David appeared to understand that models do not have to look like the real thing, while the remaining members wanted to make their model appear just like the tropical rainforest. They ultimately decided to make a model that resembled a popup children's book that was interactive and looked like the rainforest. David struggled to convey to the group that in his opinion making a biome in a box was not what the assessment was about. He drew from prior class activities in an attempt to help group members understand what he envisioned, but he was vetoed and eventually set out to work on the data by himself with occasional support from other members.

Building their model and data acquisition occurred simultaneously, with David offering support during painting and construction but then reverting to his data collection. David appeared to understand that what he was creating could be considered a model since he was collecting mathematical data from it. As both factions worked on their model there were several attempts to connect the items in the box to the pieces of paper within the cup. Ratios were a reoccurring theme that did not gain traction and did not end up in their presentation. The final part of their project was their short presentation. Their presentation lasted less than 5 minutes, and they were more than willing to talk about their model's organisms and how they moved within their box. But when the group

presented, numerical data they collected was left to the end and was discussed as an afterthought. They only briefly showed the graph David created that displayed their data.

Group B

Group B consisted of Alexandra (AL), Evelynn (EV), Liam (LI), and Penelope (PE). During their modeling warm-up Penelope described models as being copies of real objects. She mentioned that models help explain but that the explanation is to show the structure of something. Liam, Evelynn, and Alexandra all explained in their warm-up answers that models can be used for a variety of different tasks, such as showing (copy), organizing, providing answers, and presenting. Group B's narrative somewhat varied from Group A in that their conversations did not follow a linear pattern. They sporadically and rapidly moved between different parts of their modeling task, and conversations were not about modeling during the entire process. While the entirety of their conversations was not linear, their actual modeling talk was semilinear, similar to that of Group A, never moving past the use stage of their model development. Nelson and Davis (2012) and Lehrer and Schauble (2000) agreed that a model is not complete after the model is used. There needs to evaluation and revisions of the model.

Choosing Their Biome

Group B began their application assessment by determining which biome they wanted to use. The discussion that started their biome selection centered on an activity done previously in the year. In this prior activity, groups of students were stranded in various remote areas around the world. They were then tasked with identifying their biome and compiling a list of characteristics specific to that biome (climate, flora, and

fauna). Finally, they had to determine how to survive based on the resources they might have had in their environment. As Penelope started the discussion, she said, “So for the first thing, we need to pick a biome that we’re all comfortable doing because I did desert what did you do [as she pointed to Liam]?” When she said “I did” she referenced the prior biome activity. Alexandra completed the “tropical rain forest.” Liam said that he did a “deciduous. It’s the biome we’re in.” Evelynn said she had done the “the temperate rain forest.”

Since each member had a different biome from the prior project, Penelope asked the group, “Which one would have like the most animals and like species range?” as a way to narrow their choices. Alexandra and Evelynn suggested the rain forest and the group unanimously decided to use the rain forest. Their biome selection focused on the perceived biodiversity. A discussion ensued as to what organisms to include within their biome. At this point the various conversations about their modeling task began. One overwhelming theme throughout the entire time they worked on their model was their consistent, not always educational, use of computers. Participants in this group used computers for a variety of different tasks alongside tasks where they did not use computers.

Deciding Populations, Computer Use

Once they had determined their biome, they tried to determine which organisms belonged in their biome. Evelynn and Alexandra both suggested a tiger. The group continued to rattle off additional organisms such as parakeets (Evelynn), cocoa trees (Penelope), orchids (Evelynn), passion fruit (Penelope), lily pads (Alexandra), brush vine

(Penelope), and rubber trees (Penelope). As they named animals that they wanted in their model, they began to ask questions of each other about where certain animals lived and questions about species. These questions prompted Evelynn to say, “Let’s look it up.” Then Penelope, Liam, and Alexandra got their Chromebooks out and began to look up animals on the internet. Turning to their computers limited their discussion. The lack of discussion among group members could have reduced their scientific understandings about model development (Driver et al., 1994).

As they looked on the internet Alexandra suggested that they could include a monkey. Evelynn appeared to understand that there are various types of monkeys by asking, “Do we need to look up certain species of monkeys?” Penelope asked the group if white tigers might be in the rain forest. Liam shrugged his shoulders as a response but did ask the group, “Are cats in the tropical rain forest?” prompting another flurry of research on the internet. As Penelope searched up “tropical rain forest tigers,” Evelynn researched different species of monkey. She found “howler monkeys, spider monkeys…squirrel monkeys.”

As they attempted to determine which organisms they wanted in their model, the students suggested including more than one organism. Liam suggested a different species of monkey to which Alexandra responded, “Well, we don’t need two.” Penelope agreed with Liam and said, “Let’s do something else, too.” Evelynn quickly agreed with the addition of another organism. The group then began to decide which additional organisms they wanted to include. They used a variety of websites that focused on rainforest animals to identify other organisms to include. By using the internet, they

found a plethora of organisms and began to call out different species. Liam suggested cocoa beans and Evelynn suggested orchids and palm trees. Alexandra appeared to understand the connection between organisms within an environment by suggesting, “We could do banana trees so the little ba-, so the squirrels can [eat] the banana.” The only comment the group had about Alexandra’s idea was that it was a squirrel monkey and not a squirrel. Instead of acknowledging the connection between the two organisms, the group focused on the incorrect wording in her statement. This focus on the incorrect instead of being focused on furthering the academic conversation can limit what could be learned from each other (Oliveira & Sadler, 2008). While Evelynn looked on the computer, she found that “monkeys actually eat bananas.” Alexandra appeared to reference prior knowledge by stating, “Yes, they do. Isn’t that what they feed them in the zoos.” It seemed as though Evelynn attempted to connect the model to real life by remarking, “Yeah, but doesn’t mean they actually eat them in the wild.” Making sure that their model was an accurate depiction of real life is congruent with findings from Grosslight et al. (1991) and Treagust et al. (2002) that students equate their model with a correct answer.

After they had vocalized a variety of different organisms, Penelope stated, “Do you wanna do three … ’cause I don’t wanna do any more.” That is how they decided to use three organisms. Penelope then decided which three organisms they were going to include: “I’m losing my thought. You do the squirrel monkeys [pointing to Liam]. You do the, um, a-m-u- r tiger. I don’t know what, yeah, how to pronounce it [pointing to Evelynn], and I’ll do the plants.” She effectively left Alexandra out of the group research.

The group unrest that appeared throughout their modeling task appeared to negatively impact their modeling task, as they would not listen to each other, small disagreements would break out, and participants would be off task and not actively participating. These negative interactions limited their ability to have fruitful discussions and to further their understandings (Oliveira & Sadler, 2008).

Population Amounts, Computer Use

After Penelope determined which organisms the group would incorporate in their model, they again used their computers to determine the population of each organism. Using their computers to find population amounts shows a lack of understanding as to how to develop a model that they could collect data from (Cheng & Lin, 2015; Schwarz et al., 2009). Liam, Penelope, and Evelynn actively researched, read, and articulated different population amounts. To keep all of the numbers straight Penelope asked group members to repeat the different population amounts from the various years, “so we have it and we don’t have to search it again.” She specifically asked for “not the whole part, just like, this time and that population.” Table 4.10 contains their discussion about population amounts.

While Liam and Evelynn stated their various populations, Penelope noted that she “cannot find the population” for her plant. She decided “to change the flowers to banana tree. That’s what we’re doing.” Penelope frequently made decisions that were not approved by the whole group. She would make statements about changing parts of their model, and the other members typically had no comment and did not push for explanations or reasoning. According to Oliveira and Sadler (2008) students need to

challenge each other for additional information or reasoning. Learning can occur in these challenges and additional explanations. Changing organisms prompted another round of computer research without any learning taking place.

Table 4.10
Excerpts of Group B's Discussions About Population Amounts

LIAM	[Reading from computer] it's been reduced from 220,000 to in 1970s to less thsn 5,000.
EVELYNN	So in 2007—
LIAM	Oh, deforestation and hunting and captured for pet trade.
EVELYNN	So in 2006 there were 1,411 total, increased to 1,706 in 2010, and 2,226 in 2014. In the last 100 according to the latest statistics only 3,890 … tigers are left in the world, of which are 2,226 that are in India.
LIAM	200,000 in 1970 to less than 5,000.
EVELYNN	So in 2006 there was 1,411, yeah, and then in 2010 there's 2,226.
PENELOPE	Uh huh.
EVELYNN	And then right now there's 3,890.
PENELOPE	3,000, okay, there, now, okay, and then the monkeys went down, and I'm still trying to find it. I couldn't see it on here.
ALEXANDRA	That was 2018, you know

The discussion that ensued about bananas focused on what appeared in their search results, such as, "Are real bananas extinct" (Alexandra), "cavendish cultivator" (Alexandra), "What is wrong with the bananas we know?" (Evelynn), and is "death and sickness befalling bananas?" (Evelynn). Penelope, not hearing the needed information, appeared to redirect the group by saying,

> Does it say what the, we need, like, increase for what is, was in the beginning, and the decrease for what it is now, or increase, or if it just stayed the same, 'cause right now we know the monkeys and we have, we have the tigers. They keep going up.

Since Evelynn and Alexandra did not immediately find the information that Penelope desired, she modified their plant to cocoa beans, "Oh yeah, we're changing

back to cocoa beans now." Eventually Penelope found a website that talked about how "a 100 years ago about 330,000 cocoa bean trees were being replaced." Evelynn suggested that they could "just put 300,000 and up." Evelynn appeared to not understand the importance of accurate data by her comment. Penelope was unsure if the numbers she found were important, because she said, "Well, I don't know what it was saying. It was just saying 100 years ago it was being replaced by 300,000, so I don't know what that means." Eventually, they decided to use those numbers, even though they were unsure as to what those numbers meant.

Penelope was the one that began the discussion of changing the interactions between organisms. She said, "Wait, I know that tigers, you said they decreased [pointed to Evelynn] because there was not enough prey…. So that's a way it decreased." Evelynn continued Penelope's thought by stating, "So, once the monkeys decreased the tigers decreased." Penelope appeared not to fully understand Evelynn's suggestion, because she then said, "No, the monkeys decreased. The monkeys, wait, the monkeys decreased because the tigers ate too much of them." Attempting to be included in the conversation, Alexandra suggested that "the cocoa trees are getting eaten, so they're breaking down and they're dying." Penelope agreed and finalized their plan by stating, "And they're decomposing due to rapid, yes, due to rapid, um… yes, yeah, rapid decomposition …. Decomposition, yes, because of all the rain. Perfect." As they worked on computers, they had conversations about things when information could not be found on the computer.

Model Ideas, Without Computers

While the group decided how many organisms needed to be in their population, they intermittently talked about how they should make their model. Their ideas began with concepts that appeared more project-like in nature. These tended to focus on things that were socially popular. Alexandra said, “I wanna do a song.” Evelynn suggested, “Let’s do it on Tic Tok” [Tic Tok is a popular app for making short videos]. These project-based conversations could show that this group was attempting to create something that could be considered “correct,” as when Schwartz et al. (2009) found that students view models as an answer. Their project-based ideas could also have stemmed from a lack of understanding of what constitutes a model. Cheng and Lin (2015) found that even good students can struggle with model development. I would have considered these students to be good science students, and their ideas of Tic Tok or a song could be evidence of their struggle to understand how to develop a model.

Later conversations steered away from project talk to that of model construction. Penelope wondered, “How you model or show change in populations. We could use, y’all wanna do, like, bar graphs, like, you know what I mean?” Penelope appeared to understand that graphs, specifically bar graphs, had the ability to convey information about changes in populations. She went on to suggest, “Or do y’all do, like, pie charts, like timeline?” At this point it appeared as though she did not understand the purpose of a graph or how to determine an appropriate mathematical representation for their data. Similarly, Alexandra appeared to not understand the purpose of a graph when she suggested, “We could [do] pie charts.” Through her statements it appeared that Penelope

and, subsequently, the remaining group members struggled to understand that data should come from their model, and in this instance, a graph should be a way to display their findings.

In some ways their statements were similar to that of findings from Treagust et al. (2002), who found that students lacked an understanding of the connection between a model and scientific ideas. Contrary to Alexandra and Penelope, Evelynn said, “I wonder if it’s a physical model that we can touch or if it’s a graph?” She seemed to understand that there are multiple ways to represent a change in population. When Alexandra suggested a “pie graph” again, Evelynn quickly said, “No, that’s not—” After they determined what their data should look, like they then turned to model construction. Since they had various ideas as to what their model should look like they turned to prior experiences with models.

To determine how they wanted to create their model Penelope referred to a model that was created in her sixth-grade science class. She remembered

> how like in Mr. North’s last year we did, like, the earth’s crust and how we had, like, two graham crackers…. Well, we used, like, graham crackers and, like, frosting and pushed them together to, like, do, like, the crust or the continent thing, and that’s like a model.”

Liam remembered in his prior science class that “we had, like, tons, get tons of candy.” Since these prior modeling activities used food, their model construction conversations centered on foods that they could use to make their model. Alexandra suggested, “We could use animal crackers.” Her idea of animal crackers was dismissed

because “where are we going to find 3,000 animal crackers?” (Penelope). Alexandra and Penelope’s discussion over the 3,000 animal crackers aligns with research that students view models as being a smaller copy of the real thing. In their minds they needed the same number of organisms, just in a smaller size (Grosslight et al., 1991; Treagust et al., 2002). As they continued their discussion Evelynn desired something “creative,” and Alexandra suggested, “We could use jellybeans.”

Eventually they decided on jellybeans, because as a group they all liked to eat jellybeans, and they would be able to eat the ones they did not need. They also decided to use jellybeans because they could show how the populations changed by eating the jellybeans or adding more jellybeans (Schwarz et al., 2009). As they discussed what to do with the jellybeans, other ideas emerged as to how their model should appear. They discussed a variety of ideas incorporating grass, plants, popsicle sticks, cups, cotton balls, and an assortment of other materials in an apparent effort to make sure their model looked like a tropical rain forest. Table 4.11 contains a series of statements that centered on determining the appearance of their model.

As they determined what was needed to complete their model, Penelope suggested, “We can get, like, pine needles from trees.” Liam then suggested that they could “list out what everyone can bring in.” From here, a discussion ensued on a variety of materials that each person could bring in. Evelynn said, “I can bring in the animals,” referencing plastic animals that could be bought at a store. Alexandra said that she could “bring the cardboard box,” and “I can bring coffee so we can, like, glue it to the trees.” Alexandra seemed confused about what food comes from cocoa, because she said,

"Yeah, and then we can glue cocoa, glue actual coffee beans. "Although it appeared that Alexandra mistook coffee for chocolate, her thought was to "put them together and, like, two pieces glued together so it looks like one of the pod things that live on the trees." Penelope suggested that she should "go to Home Depot and get some trees, not like big trees but, like, the little shrubs," and "I'll bring then sod and the plants and then maybe the cardboard box." Liam and Alexandra both offered to bring in jellybeans. While they did have an abstract component, the jellybeans, they also desired to make parts of their model appear like a rain forest (Grosslight et al., 1991; Treagust et al.,2002).

Table 4.11
Excerpts of Group B's Discussions on Model Appearance

EVELYNN	I have an idea. We can make, like a, like a surrounding that looks like a forest on a cardboard.
ALEXANDRA	Yeah, like we could cut out trees and stuff.
PENELOPE	We could get, um, those cardboard boxes. Like, we could get like, kinda like the big, like the boxes, or whatever it is, cut out the front so it kinda looks like a TV. Like, you know what. I mean, like, where it's like, there's like a frame and, and then decorate the inside of that.
EVELYNN	To make it look like a TV.
PENELOPE	Have the three cups in there. We could have the three cups, and then this is like our cocoa beans.
LIAM	And when deforestation comes—
PENELOPE	We could like take it out.
LIAM	Make it, yeah, take the trees out and then take some jellybeans.
ALEXANDRA	Oh, wait, and then we can use plastic clear cups, like the Solo cups, like the plastic — and like, put an image of what that is on the cup on the outside.
LIAM	Wait, so we had an idea for the trees. We could use these [popsicle sticks].
ALEXANDRA	And then we could use cotton balls, then dye, it dunk them in, like, green water and make them green, and then they become green, and then, and when we can use — toothpicks as the branches.
PENELOPE	Or I could go, like, to Home Depot, like, I'm already going and buy, like, one of those tiny little trees and break them off and use, like, you know what I mean? Like, instead of putting them in dirt they can be, like, trees. I don't know.

Their final model idea centered around a box with sod and jellybeans in cups. Penelope described their model by listing things they needed:

> This is for the, so we're gonna get a big gigantic box, and we're putting the sod in there with some like little plants, and we have cups to represent, like, the certain animals and show how, like, the jellybeans die. We replace them so they decrease [moving her hand away from an imaginary cup], and if we put them back in, that's like how they kept increasing due to deforestation, and we'll have that.

Since they planned to use grass and live plants for their model, they decided they needed to have a way to water their plants like a rainforest. Alexandra suggested a plastic bag with holes to make it "look like it's raining." When no one acknowledged her suggestion, she said it again:

> Oh, Penelope, I just thought of a good idea, Penelope. We can put, like, you know how, like, rain forests, it rains, right? We could put, like, a plastic bag and poke a couple holes and water's just going to be dripping onto grass, so it's watered, and it looks like it's raining.

When Penelope offered a different suggestion of cold cups and condensation, Alexandra immediate rejected that idea: "Uh, no, we're gonna do what I just did …. I was thinking of doing it in a Ziplock bag." The inability to have a constructive conversation about suggested ideas within the group negatively impacted the group's collective learning (Bruffee, 1999; Driver et al., 1994; Oliveira & Sadler, 2008), and it also negatively impacted group morale. The desire to have rain in their box would be similar to that of a rainforest. Even through their disagreements, they were clearly not only concerned with accurately representing the biome, they also wanted parts of their biome to function in a similar manner (Grosslight et al., 1991; Treagust et al., 2002).

Online model ideas, computer use. Computers were not only used to identify population numbers and for shopping, they also used their computers to get ideas as to how to construct their box and what it should look like. Penelope directed, "Y'all search up ideas on Pinterest or whatever for box ideas," and "so search up cardboard box project." The conversation in Table 4.12 focused on an idea they found online.

Table 4.12
Excerpt of Group B's Discussion on Online Model Ideas

ALEXANDRA	Ah, and then we could make, like, a little twig nest to, like, represent birdies. Oh this is cool. Look, I think they're doing the same thing we are. Look [turns computer].
PENELOPE	Whoa, dude, yeah, but ours is going to be better because we're gonna have sod.
ALEXANDRA	They have fake grass.

Rough draft, computer use. As Alexandra looked for ideas on Pinterest, Evelynn took it upon herself to create a rough draft of their model on the computer (Figure 4.9), based on their prior discussion of what they were bringing in. She verbalized the different components of her online rough draft. "Okay, so we have our box, right? Look, excuse me sweetheart." Since no members were listening to Evelynn, she snapped her fingers and said,

> So, we have our box, okay, then this, so it looks like it's unique right?... So, then we have our cups. So, there's the box, right? We're gonna draw a little box…. So, there should be and then there's going to be cups.

Penelope appeared to not be paying attention, because she got cups out of the classroom supply bin and said, "I say we do these … to hold our jellybeans. I vote these." Evelynn appeared to not take kindly to Penelope's inattention and said, "Look." She then

snapped at Penelope and pointed to the computer screen that she had turned around. Ignoring members and snapping to get members attention could be considered negative interactions that were not beneficial to the creation of their model or to the flow of learning (Bruffee, 1999; Driver et al., 1994; Oliveira & Sadler, 2008). The computer-generated image that Evelynn created was what their final model resembled. This two-dimensional image could be described as a visual model (Gilbert, 2004; Harrison & Treagust, 2000). Once the rough draft was made, no additional scientific information was acquired that would have caused a change in their model. It is unclear if this group would be able to revise their model, as there was no attempt at gaining additional scientific information.

Figure 4.9 Online rough draft.

***Other computer use*.** While this group used computers for purposes related to their model, many times they used computers for reasons that had nothing to do with their

model. Every so often Pinterest was used, not to look up project ideas, but for entertainment. Multiple times Alexandra would look up memes and funny pictures. She would then get her group members off topic by showing them the various things she had found online. There were also times she would go to Instagram to view memes because "the memes are so more funny." Alexandra's apparent lackadaisical attitude toward the development of their model negatively influenced the remaining group members. Lee et al. (2015) said that the way that each student learns within the group can have an impact on the final model, just like Alexandra's frequent nonmodeling conversations impeded progress on model development.

Material Acquisition, Computer Use

Not only did they use computers to gather population data, they used their computers for online shopping to procure materials for their model. They used a variety of websites to shop for materials ranging from jellybeans to sod. Alexandra's statement of, "Oh, let's do that now Amazon shopping," started online shopping to procure materials. Suggestions for searches were tossed around, Evelynn suggested, "Search up, like, orange jellybeans." Penelope attempted to refine their search field by stating, "Go on Amazon, go on here [taps on computer], go on Amazon and search up big things of jellybeans. See how, like, big of a container we can get for, like, the cheapest." She continued,

> You search up multi, multi, sear— like,… not multicolored, like, "assorted jellybeans." Like, no, go on here [taps on computer]. Go on Amazon. Search up

> Jelly Belly's, 'cause that's, like, the name of the brand. Jelly Belly. Big containers. "Bulk." Like, search up "bulk," and then it will show you ones.

They also shopped for plastic animals, but Evelynn said, "No, they have those at Tractor Supply." Penelope wanted to incorporate sod inside the cardboard box because "It'll just, it'll look better, waste less paper, and it'll work [gets computer]. I'll just go on here and search up, um, sod." While they shopped online for items, they also utilized the material bin within the classroom and identified items that could be brought in from home.

Material Acquisition Without Computers

As Evelynn and Alexandra shopped for materials online, Liam and Penelope worked on creating a list of materials that could be brought from home. Occasionally the sides would interact and would offer online shopping advice or suggest materials that could be brought in from home or from brick and mortar stores. Penelope suggested, "color papers, scissors, and glue," while Alexandra said she could bring in "a bunch of cardstock." In order to make their box more realistic, Penelope mentioned that "we might need acrylic paint so just we can cover the area up." As Evelynn shopped for plastic animals Penelope decided that it might be easier to print pictures of the organisms. Penelope asked, "Could we print some of the tigers and everything instead of bringing like actual figures?" Throughout all their material acquisition, there was a desire to bring in things that would make their box look like a rainforest (Grosslight et al., 1991; Treagust et al., 2002).

Graphing Data

As the group determined which items to bring in and what they wanted their project to look like, they began to discuss how they wanted to graph their data. The discussion was different than the prior discussion about graphs. In the prior discussion they were trying to identify how to create their model. In this section on graphing they were strictly discussing how to graph their population numbers. Evelynn mentioned that their graphs could look "like the bean thing but gonna [moves hand up and down]." Penelope suggested that "we're gonna use size graph, um, we don't know if we're gonna use pie charts or bar graphs." The discussion of graphing was intertwined within several other conversations, but Penelope once again asked, "So, should we do a pie or bar?" Without a direct answer Penelope quietly worked alone creating a variety of graphs to display on the side of the box. A conversation of graphing could have provided clarity of which type of graph would be most appropriate (Bruffee, 1999). She first created line graphs (Figure 4.10) then created a series of bar graphs (Figure 4.11). After the graphs were complete the group then began to make their model.

Making Their Model

Model construction began by sorting jellybeans and eating the colors that were not needed. "Okay, do you wanna, okay, um, do you wanna sort the colors right now and eat them?" Alexandra asked. (See Figure 4.12). As they sorted jellybeans Penelope began to measure circles on the lid of the box and said, "This is how big we need the hole," for their rain system. Styrofoam cups with holes in the bottom sat in these large cutout circles so that they could be "fill[ed] up with water."

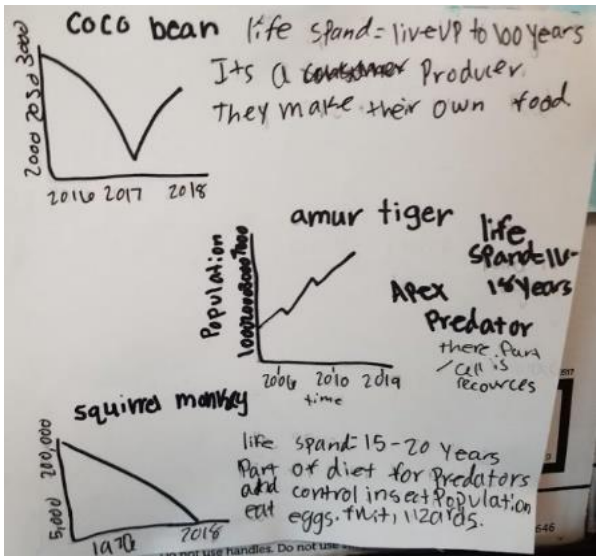


Figure 4.10 Line graph.

Figure 4.11 Bar graph.

Figure 4.12 Sorted jellybeans.

The first time they attempted to make it rain a disagreement arose within the group. Alexandra was worried that water would flow too rapidly out of one of the cups because “that cup is still deformed it broke…. Water is gonna come out of if it’s broken. It’s like cracked.” Penelope’s response was to tell her to “shush.” As the water was poured in, Evelynn remarked, “It’s flooding that ... cut the holes too big. That one works perfect.” As Penelope started to make a new cup with smaller holes, Alexandra attempted to grab what Penelope was working on. Throughout model creation there was a recurring struggle between Alexandra and Penelope or Evelynn. These continued negative interactions, both verbal and physical, such as taking things from each other, seemed to hinder the progression of their model. As the struggle grew, there appeared to be fewer attempts to generating new ideas (Oliveira & Sadler, 2008).

As they worked on making it rain within their box, they also focused on getting enough light into the box. Penelope decided that they needed to cut out the front of the

box allowing for light to reach further into the box. Penelope and Liam discussed how large the opening should be, and Penelope appeared to understand that once they cut it the box they could not put it back. She said, “I know. I just wanna do it high, pretty high right now, so if we need to cut it lower we can.” They also discussed additional ways of getting extra light into the box. Penelope suggested, “What if we did, like, little dots on the top so light could come through.” The location of holes was important so that it appeared as though light was filtering to the forest floor from the canopy of trees above (Figure 4.13).

Figure 4.13 Filtered light holes.

By removing portions of the box and allowing more light, it appeared that they could revise their model so that the light inside was congruent with what they might find within the rainforest (Schwartz et al., 2009). When Alexandra suggested cutting holes in

the side of the box ("This flap thing, like, right here we could"), Penelope quickly put a stop to that idea. "No, trees don't come from the side. They come from, no, and the graph's going to be covering it anyways." Penelope appeared to be concerned not only with the accuracy of the filtered light through the trees, she also seemed to want their model to be aesthetically pleasing. Having their model be congruent with what it might look like in the rainforest mirrored what Grosslight et al. (1991) and Treagust et al. (2002) uncovered with middle schoolers believing that a model should replicate the object being modeled.

As they worked on their box, Penelope suggested that "we should paint this blue and, like, paint some white clouds on there." When any writing was to be done on the box Penelope would say, "It needs to match…. You need to match the theme," and, "It'll be two separate handwritings. That's not okay." Multiple times throughout model creation Penelope appeared to be more concerned with the aesthetics of their model than with the functionality.

Ratios

As they worked on constructing their model, they often talked about the number of jellybeans that were needed. When concern arose about not being able to procure enough jellybeans Alexandra reminded Evelynn of her idea for using ratios, "Yeah, but if we did, like, what you said, like, ten, ten, equals—" After that the group periodically discussed the jellybeans in ratioed terms. This use of jellybeans to represent a subset of each organism's population could be considered an analogous model, because it takes something tactile and familiar and relates it to something abstract (Gilbert et al., 1998).

Evelynn suggested, “How about we can make a key cause, like one jellybean equals, like, a hundred.” Penelope seemed to have difficulty grasping the concept of ratios, so she suggested cutting jellybeans in half so they would have more jellybeans to use. “Half of one is a 100, full is 5,000, or stuff like that,” she said. Table 4.13 shows an example discussion of ratioed jellybeans.

Table 4.13
Excerpt of Group B’s Discussion of Ratios

PENELOPE	We could make, like, one jellybean, like, worth a thousand. Like, it doesn’t really matter.
EVELYNN	‘Cause the tigers do decrease by one thousand, but then increase a thousand.
PENELOPE	And then we could cut the jellybeans, so like, the cut jellybeans are half of a thousand.

The discussion of ratioed jellybeans took on a larger role as members of the group realize that they only had a certain number of jellybeans. Evelynn noted that “there’s 23 black ones…14 [white jellybeans]” and Liam stated that there were “16 orange ones.” Evelynn seemed think they needed the same amount of each color jellybeans: “Okay, so we need to take away black ones, ‘cause we have twenty something.” Acknowledging Evelynn’s apparent confusion, Penelope told her, “So, the, no, but they’re all different numbers, Evelynn. They are all different numbers.” Penelope gave the impression that she understood that they did not need the same number of jellybeans, but she struggled to comprehend that each jellybean did not have represent the same number. Penelope stated, “One’s a hundred, like, every jellybean is 100.” Throughout their discussions Penelope seemed to understand a need to create ratios, “’cause I cannot put 1,000…. I can’t put 5,000 jellybeans in here.” While she appeared to understand, she struggled with how to

calculate the number of organisms each jellybean would represent, so that task fell to Liam.

Seeming to understand how to complete the mathematical calculations, Liam began determining the jellybean ratios:

> I say 114. If we don't have enough orange, we can just make those 200…. We have 34 white. We'll have to make those equal to, like, 200,000…. So, if each of these beans, right, jellybeans were 6,000, then it would be 214 beans.

As Liam attempted to determine how many organisms each jellybean represented, members displayed difficulty understanding exactly how to determine ratios. The section of transcript in Table 4.14 shows the difficulty Liam and Penelope had in trying to connect the number of jellybeans and organism populations.

Eventually the discussion ended with no real conclusion, Alexandra, Evelynn, and Penelope went back to their model, and Liam was left to "the math." After he finished calculations, he began to explain how many jellybeans they would need to add in and taken out from each cup "so right now we have 16 orange beans so they each would have to equal 88 so if they each equaled 88 then we would need 44 beans…at the end so we'll just have to add…88 so we only have to add 20."

Table 4.14
Excerpt of Group B's Discussion Illustrating Difficulty With Ratio

LIAM	'cause in the thing it said there's, there used to be like 2,000, and then it went down to less than 5,000. So nothing.
PENELOPE	What if we made each bean just –
LIAM	So do we only need 5,000?
PENELOPE	Okay, so we need 5,000 in one cup, 'cause we go from the highest number – i have the graphs – so we, one cup, we need 30,000 or –
LIAM	Yeah, 3,000,
PENELOPE	3,000, one. We need 1,000, one, we need –
LIAM	And then squirrel, one can. We need 200,000.
PENELOPE	We need 200,000 for one squ— we need 200,000 for one squirrel. We need 3,000 for the cocoa beans, and we need about, we need 1,000 for one cup – so i say five for each one.
EVELYNN	Huh?
LIAM	So if there's 34 jellybeans – and we have – so there is these, um – jellybeans, 5,883 monkeys – then we won't have enough unless we open another bag.
PENELOPE	Well, just do whatever's easiest 'cause i just don't want to put too many in a cup. I say just do 500 for each jellybeans, then it would be easier to just count how many.
EVELYNN	And we can cut them in half if we need to show a different number.
LIAM	So if, if each of these are 5,000, then it's equal to 1,700.
ALEXANDRA	Is that the number we have?
PENELOPE	Do you think we should open another, the other bag?
ALEXANDRA	I feel like we don't need that bag.
EVELYNN	Well, yeah, we do.

Again, confusion ensued as to why the numbers were different for the different colored jellybeans. Penelope stated,

> But if they do, that's perfect, okay? Wait, calculate how much we have with our beans now, and do it for 500 each, and then see if that's too little, and then we could probably make them a thousand each, and if it's a full one, and if it's a half, do a hundred.

Again, Penelope stated her idea: "See, 500 for each bean, and then if it does, that's perfect. If it doesn't, well, and it's too little, we could do a thousand for each bean, and then half a bean would be 500." In an apparent attempt to help Penelope understand

why her idea does not appear to work, Liam calculated how many jellybeans would be needed for each color. He again told Penelope how many jellybeans they would need if each bean was worth 500.

> So if I we did 500 for each one, for the jellybeans, for the monkey, it would be 17,000. So, do you want to do for the monkeys to do 5,882? 'Cause if you do that it will be like 199,000, like 800 something.

Again, Penelope stated her ideas: "Well, we could just do 500 for all of them," and, "Okay, see how many we need to each, on like, if how many, if they're all 500 then how many each we need in a cup, 'cause –." As Liam worked, she then apologized, "Sorry. I'm making you do all the hard work. I'm just not good at math." Appearing still to not understand, Penelope stated, "Yeah, we can do whatever, whichever is the easiest." Even though Liam completed the mathematical calculations per Penelope's request, she still did not understand. Had Liam provided explanations, then maybe it would have alleviated Penelope's confusion (Bruffee, 1999; Driver et al., 1994).

Liam, appearing to realize that Penelope still did not understand the ratio between the number or organisms and the available number of jellybeans, suggested cutting the jellybeans into pieces to make more jellybeans available. He continued the conversation of how many jellybeans or jellybean pieces to use by himself. He said,

> I found a better idea. If we cut all of the white ones in half, it would be 68, so then we could just do that, and it would be easier for making it, when we take them out…. Yeah, if you did 200,000 divided by 68, it would be 2,941.

Penelope, evidently still be struggling with rationalizing the ratio of jellybeans to organisms, made her thinking clearer by saying, “But the only thing is, all of the jellybeans have to be the same number. Like, all of them that are split in half, all of them equal the same number.” Liam attempted to work within Penelope’s understanding and suggested cutting beans in quarters, “so if we still had half a bean that would be 2,941, and then if we just had quarters, it would be like 1,470, so if we just added those to be 4,411.” The more he attempted to work within Penelope’s understating, the more confusing the numbers became:

> So we, 16 tigers, so, so each of those are equal to 243, 243, so that we can, but that’s for the 3,000, so then we can have 16 for 1,411 and just add more to make it…. We can just add eight more tigers… So, for the white ones we just need to split them in half and add one fourth.

In an apparent attempt to set Penelope on the right mathematical pathway, he said, “Like, it doesn’t really have to.” Penelope appeared to understand what Liam meant, as she said, “Oh, so it’s allowed to be like the jellybeans for one thing is like—” to which Liam replied, “Yeah, because they each have different populations.” From this point on Liam and Penelope were in agreement as to how to determine the number of jellybeans for each organism.

Bruffee (1999) said that for learning to occur within a group, members have to come to consensus. Liam and Penelope came to a consensus, but the data did not reveal if Evelynn and Alexandra also understood how the ratios were calculated. Had Liam been more vocal in explaining how he understood ratios, it could have saved the group time

and unnecessary confusion. Liam understood how to determine the ratios but attempted to work within Penelope's realm of understanding, instead of providing an explanation for his reasoning. For students to work effectively together they need to be able to communicate information to aid in the learning of their group members (Lee et al., 2015)

Preparing for Their Presentation

After they completed their model (Figure 4.14), they prepared to present their model. Their preparations began by procuring water for their rain cups and searching additional information online about their organisms, such as what the organisms ate, habitat, and lifespan. After their information was found they poured water into the cups on the lid to make sure it still worked. In their haste to practice making it rain the jellybean cups were left in the box. Their paper animals were now water stained and their jellybeans sticky. They reviewed one final time how many jellybeans or jellybean pieces need to be added or removed from each of the cups during their presentations. After finishing touches were complete, they had a few opportunities to present for small groups of peers within the classroom.

Figure 4.14 Finished model

Presenting Their Model

Group B's presentation centered on reciting information they had found online while simultaneously adding and removing jellybeans. Table 4.15 contains a transcript of their presentation. This first presentation highlighted the information that they found online. As they discussed population changes, they would move 10 jellybeans, but made no correlation between the number of jellybeans and the actual populations. If the population decreased, they removed 10 jellybeans, it the population increased they added 10 jellybeans.

Subsequent presentations barely changed from the original presentation except for the jellybeans. Only once in the second presentation did they make mention of the number of beans being added to the cup. The other two times beans were moved received no verbal acknowledgment. Penelope stated,

> So, we're gonna add about 10 jellybeans just to represent the ones that went up, but they grew in their populations because they had to spread out, 'cause there weren't as many preys in certain areas, so they had to spread out and their population went up.

In the final two presentations they only verbalized jellybeans being added to the cup, but the numeral accuracy was nonexistent at this time: "Of course, our population of our tigers grew, so we're gonna add a couple jelly beans." Penelope also said,

> So right now our tigers, they increase, so we're just gonna add a couple jellybeans that numbers, it was, um, the reason that they grew was because they didn't have certain prey in some areas, so they had to grow. Oh, they had to go different

places, why they grew now with our cocoa beans, they did decrease due to rapid, um, de-, co-, decomapnization [sic].

Table 4.15
Transcript of Group B Presenting Their Model

PENELOPE	In the beginning –
ALEXANDRA	There was –
PENELOPE	Water, kay? So –
ALEXANDRA	So. now it's raining.
PENELOPE	So. we used our tigers, our cocoa beans – Crap. We hurt Fernando [the plant]. And our monkeys, so in our populations are tigers, were the only ones who increased in the populations. Our cocoa beans decrease, and so did our squirrel monkeys. So the life span of cocoa bean, they can live up to 100 years. So, that really shows that it takes a while for them to decrease, and the reason for them decreasing was the rapid decomanation [sic], if that's, yeah, that's how you say it, and they also are producers and they make their own food.
EVELYNN	Yeah, I, okay, so, um, amur tigers have the largest home prey spread increase in the population due to low prey.
PENELOPE	Due to low prey they had to spread out, and they had to find more places so that the population went up in multiple different places.
ALEXANDRA	Okay, the cocoa beans, uh, can't read that.
PENELOPE	The squirrel population decreased because there weren't enough males for them. I mean, there weren't enough females for them to reproduce with, so the males, and they also took over because there're a lot more males than there were females, um, leaving. Not that many, like, natural, I mean, resources for them to, like, eat, survive, so the male or the female monkeys decreased in the populations, okay?
EVELYNN	So, in 1910 the populations of squirrel monkeys was 200,000. In 2018 it was between 5,000 and 200,000, and it was the same in 2019.
ALEXANDRA	The amur tigers increased, uh, in 2006 there was a little over 1,000, and then in 2010 there was a little over 2,000, and then in 2019 there was a little over 4,000.
EVELYNN	And then that cocoa beans, in 2016 there was 3,000, in 2017 there was in between 2,000 and 2,050, and then in 2018 there was a little over 2,050.
PENELOPE	Okay, and then for our monkeys [gets cup out of box], since they decreased we get the monkeys, so they, of course, decrease because there were not that many, like, females as we already said, so we are going to take 10 of them away, and each half jellybeans were, so then we'll have 10 left because they decreased all the way down to –
ALEXANDRA	No, it's 14 all right?
PENELOPE	5,000 and they started in 200,000 [puts cup back in box], and then with our cocoa beans, they started at 300,000 and went down 2,000 [gets different cup out of box], but since our amur tigers, they eat, increase, we have to add about 10 jellybeans, 'cause they are over 2,000 and they started at 1,000 and went up to about 4,000 tigers [puts cup back in box], and that shows how they increased and decreased in their populations.

The omission of jellybean population amounts revealed an apparent lack of understanding with the importance of data collection because they acted unconcerned in the movement of their jellybeans. During their presentation it appeared as though they lacked a connection between what was happening in their environment, based on what they found online, and how many jellybeans to add or remove from the cups. This behavior mirrors findings by Komis et al. (2007), who noted that students in their studies also struggled to make connections within the various components of their models.

While this was written to be read in a linear manner, this group did not actually work in a linear manner. While they started with choosing a biome, their computer use occurred frequently in the beginning days and then sporadically toward the end. Their use of computers varied from determining organisms and their populations to online shopping for materials, looking up project ideas, creating a rough draft of their model, and entertainment. As they used their computers, they would interject ideas for their model and what materials they might need to purchase or bring in. As they were deciding what their model should look like and what materials they needed, Penelope graphed their population numbers that they found online. She appeared to not make the connection that data collection was to come from their model, similar to activities done in class. Additionally, no other group members vocalized any discontent with how they were acquiring their data. It also appeared as though no other group members understood how to collect data from their model. After their data was collected and their graphs were made, they then started to construct their model. As the group worked on their model

they continually suggested or added new components to their model. They had to procure additional materials from other groups or from the class supply bin.

From the time population amounts were identified online, which they considered their data, the group periodically suggested using ratios to represent the number of organisms in the population and the number of jellybeans available. The mathematical part of determining how many organisms was represented by each jellybean in the cups was left up to Liam. There was much discussion during this modeling task over the number of jellybeans needed and the more frequently the discussion came up the less stringent they were on making sure they had the correct number of jellybeans.

The lack of care for the jellybean amounts was apparent during the group's presentation. They attempted to make sure they had the correct amounts as they prepared, but once they presented, the accuracy of their jellybean numbers was forgotten. Jellybean acquisition or subtraction became haphazard. As the group prepared to present and as they presented, they were more concerned with how their model looked and how it rained within their box than with understanding and communicating how they thought they collected data from their model.

Final Thoughts on Narrative Thinking

In answering Research Question 1, both groups started with identifying a biome and the populations they wanted to use for their model, but both groups differed in how they arrived at their final product. Both groups relied on knowledge of prior modeling experiences for completing their model. David utilized his prior knowledge and experience with data collection in order to develop the data portion for his groups model.

Group A, mainly David, relied on a population sampling activity done in class as apparent inspiration for his version of the model and subsequent data collection. Group B relied on knowledge from a prior school year that used graham crackers to model earth's crust. Each group used computers but Group B relied on computers more than Group A. Group B used computers for acquiring their population data, entertainment, and ideas, while A used computers to make sure that the organisms they chose lived in the same area and would interact within that area. As in all group activities there was an overlap in conversations. These overlaps created confusion within each group and a visually sporadic transcript. Fosnot and Perry (2005) described groupwork as being inherently disorderly. Even though their work appeared chaotic, it was still important because it could provide opportunities for students to deepen their understanding of the interactions between populations within an ecosystem. Even with the confusion in Group A they still managed to divide and conquer tasks. As they worked on tasks and discussed new ideas, they frequently worded suggestions or ideas as questions. They appeared to be very concerned with doing things right. Having their model appear to be right is congruent with Schwarz et al. (2009) findings that some students view models as correct answers. As Group A worked, they were willing to help each other and were focused on their task. Group B's conversations showed a struggle for dominance within the group. Members had difficulty working together and would frequently argue about who was supposed to complete a task and how the task was to be completed. These frequent negative interactions could have hindered their learning or limited their progression as they created their model (Oliveira & Sadler, 2008).

The disconnect in Group B was evident in their planning process. They had a general rough draft of what they wanted to do, but any changes were done quickly, and the group consensus was not obtained before changes were made. The exception was the rain system they created. They did test how the cups would work to simulate rain before they made major changes to their project design. This contrasted with Group A who planned out everything they wanted to do and would check for agreement within the group before proceeding.

Students within each group struggled to understand that the data they were to collect was to come from the model that they created. This problem mirrored a study done by Komis et al. (2007), who found that students struggled to make connections between two factors within a model. The exception to this was David, who understood that the model was not something that needed to be built within a box but that it was something that could be used to gather information about their populations. His utterances during their modeling task mirrored his views that he wrote on his warm-up questions. He frequently tried to help his group members comprehend his understanding of models by referencing the class activity on population sampling. Since David had a different understanding of what the model could be, Group A's narrative divided in the middle. Members would interject within each story, but David's main narrative revolved around the data he collected, while Corey, Isabella, and Wendy's narrative revolved around the model they were building. Group A attempted to make sure the populations within their model were in proportion to populations found in nature. They discussed at length the appropriate number of organisms that needed to be accounted for in the

beginning and then at each round of data collection. Group B paid no attention to the proportion of organisms within their population. They gathered numbers off the internet. That was their data, and there was little discussion of whether that would be similar with nature. While Group A's data collection may not have always been accurate, as the number of pieces of paper that was to be added or removed was occasionally disputed, they were consistent in how they collected and recorded their data. Group B's population numbers did not change. What they found on the internet is what they presented. Yet when it came time to determine how many organisms were represented by each jellybean and how many jellybeans to take out or put in during their presentation, they were willing to alter information to make understanding their numbers easier or to speed up their presentation.

As each group worked, Group A's cohesion was a stark contrast to that of Group B. Group A helped each other complete tasks, and if there was any down time, they would ask what else needed to be done. On the flip side, Group B had several instances where only one or two members were doing all the work. Alexandra spent a significant amount of time looking on Pinterest, Amazon, Instagram and doing work for another class. Evelynn who sat by Alexandra would get distracted by what Alexandra was looking at, and conversations would ensure that did not pertain to any part of their model.

To understand what their conversations revealed about their use of modeling, in the next section I describe my examination of student talk pertaining directly to the model. While examining the modeling conversations of both groups, I observed some similarities. The initial intent was not to identify similarities, but it was uncanny how

similar both groups used modeling. From these similarities three main aspects to student modeling emerged from both groups. First, the groups utilized prior modeling experiences in the beginning development of their model. Second, their modeling displayed their understanding that models have two main purposes, it was a replica to show their biome, and it was a place to house data. Finally, the model was used as a way to show what they found in their data. In the sections that follow, I describe various components of how the students collaborated using modeling.

Prior Experience

Group A and Group B both referenced prior experiences in their model creation. David from Group A referenced a population sampling activity done prior in the current school year as an example for how they could collect data. He told his group, "the lab with the beans. … It needs to be like that." As they began to discuss data collection he suggested getting "like beans and stuff." As David referenced the beans again, he told them, "That's what we've kinda gotta do with this." This group, at David's direction, utilized prior methods and materials in order to generate and gather data. The group set up their data collection to mimic the population lab. The group created stories for each organism that would determine the number of papers added or subtracted from the cup. Removing the papers from the cup and tallying the organisms on their data sheet was similar to the activity done in class, which started with identifying the original population amounts. From there, Group A created a table similar to the directions for the population sampling activity. The activity gave instructions for how many beans to add or remove in a year, Group A developed a similar series of statements and actions. Furthermore, their

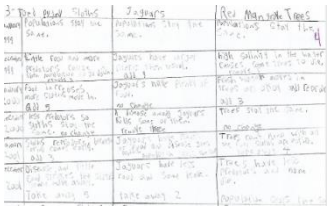
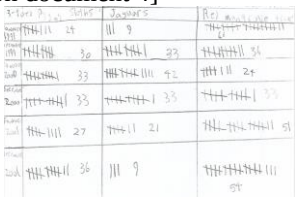
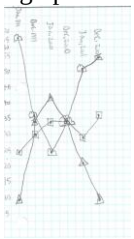
procedures, data tables, and mathematical representations mirrored the activity done in class. Table 4.16 illustrates the similarity between the population activity and Group A's data collection. When the students completed the population sampling activity, it was referred to in class as a model. When Group A referenced the activity as inspiration for their data collection, they did not make the connection that what the group called data collection could be considered their model because they could collect data from it. Because of Corey, Isabella, and Wendy's views of models and their inability to challenge each other for additional information, the connection was never made that the paper and the cup and the stories they created could be their model.

Group B used a prior science activity from a different grade and the graphical part of population lab to help guide their modeling. Penelope recalled an activity that was done in a prior science class:

> We did, like, the earth's crust and how we had, like, two graham crackers.… We used, like, graham crackers and, like, frosting and pushed them together to like do like the crust or the continent thing and that's like a model.

Penelope's recollection of using food created a reference for developing their model, which led Group B to discuss using edible items as part of their model. Alexandra suggested using animal crackers, Sour Patch "kids," and then "jellybeans, or we could do gumdrops."

Table 4.16
Activity and Model Comparison

Snips of Population Activity Directions	Group A's Data Collection
Put 92 white beans and 8 black beans into the bag. The white beans represent rabbits, and the black beans represent foxes. Note that these numbers are FOUR times the observed number of animals in the example above.	DA: How many sloths do you think there should be to start out [overtalking]? DA: 'Cause there needs to be an equal number [overtalking] of thirty three or more, all animals IS: Thirty-three, DA: I mean ninety-nine, WE: Not ninety, we don't need to put a hundred. DA: Yeah. WE: We don't need that many. DA: I need to cut out that many.
Start with the information for the first date in TABLE 2, October 1997. Add and remove beans as directed to represent the changes described. Sampling Date / Rabbit Population / Fox Population October 1997 / The winter was harsh, and food was inadequate. Many rabbits died. Remove 10 white beans. / Foxes ate pheasants as well as rabbits. Fox numbers increased. Add 2 black beans. April 1998 / Rabbit population increased with the decrease in predators. / No change in population October 1998 / Food was plentiful. Rabbits moved into the area. Add 15 white beans. / Foxes had larger litters than usual. Add 2 black beans. April 1999 / Disease killed many rabbits. Remove 8 white beans. / Food supply was low due to disease among the rabbits. Some foxes left the area. Remove 3 black beans. October 1999 / Spring came early. Rabbits could breed earlier. Add 12 white beans. / Food was plentiful. Foxes moved into the area. Add 8 black beans. April 2000 / No change in population / Inadequate food to feed the increased fox population. Some foxes moved out. Remove 4 black beans. October 2000 / The farm was opened to hunters, who killed pheasants. Foxes ate more rabbits. Remove 14 white beans. / Hunters shot some foxes. Remove 2 black beans.	DA: How many sloths should move away? IS: Five sloths per year. Oh, wait, six trees die, okay, three sloths per year. 
Shake the bag with the beans.	IS: Why do we need cups> DA: Or one cup – IS: Why? DA: To put everything together in, to take it out and – IS: For our model.
Select a bean without looking.	DA: [picking different colors of paper out of the blue cup] DA: Wait, um, would you count these out and tell me what they are? [hands Wendy the blue cup]
Record your results in TABLE 3 in the Data and Observations section. Population Sampling Date / Rabbits (White Beans) Observed / Rabbits (White Beans) Total / Foxes (Black Beans) Observed / Foxes (Black Beans) Total October 1997 April 1998 October 1998 April 1999 October 1999 April 2000 October 2000 April 2001 October 2001	DA: [marking on document 4] 
Graph your data on FIGURE 1 on the next page using the data from the population samplings that you recorded in TABLE 1 & 3. 	DA: Like this, should we do a graph or should we just leave it like this? [holding up document 4] 

Group B eventually settled on jellybeans to represent the different populations of animals in their rainforest. When Evelynn mentioned the population sampling activity, she did so as a reference for how to represent their data mathematically. She suggested that their graph is “kinda gonna be like the bean thing but gonna [moves hand up and down].”

Prior experience with a variety of activities within the classroom also appeared to influence materials needed for data collection. During the school year materials were carried around the room in plastic cups in an effort to minimize messes. Interestingly, both groups utilized plastic cups as part of their data collections. Not only did activities influence their modeling, class procedures also influenced modeling. It is important for teachers at the middle school and elementary level to be explicit in their teaching about models and modeling. This research showed that students utilized prior experience in modeling. If prior modeling experiences focus on common conceptions such as models are replicas (Grosslight et al., 1991; Treagust et al., 2002) and only focus on three-dimensional models (Lee et al., 2017; Grosslight et al., 1991), then students will continue to have difficulties developing models that are abstract (Schwarz et al., 2009). Even though each group referenced prior experiences that did not replicate real-life objects, when it came to building their model, they made consistent efforts to make sure their model looked like their chosen biome (Grosslight et al., 1991; Treagust et al., 2002).

Models' Purpose

Both Group A and Group B's modeling showed their understandings that models had purposes other than data collection. Their boxes were decorated and assembled to represent mini rainforests. Then they were used as a vessel to display or contain data.

Group A

Because group A viewed their model as an exact replica of their biome (Grosslight et al. 1991; Treagust et al., 2002), they painted treetops and they spent time adjusting paint colors and refining their painting technique to achieve the look of leaves. Corey advised, "No, you just you dip, like, you dip it in all three of them, and you get just, like, a little bit of each of them."

Group A also needed a sloth, rain, and water source. The sloth proved to be difficult because David did not bring in a plastic sloth. He brought in a plastic gorilla. Corey wanted to make sure that the plastic gorilla looked like a sloth, so she suggested, "We can paint that to make it look like a real sloth. What I was thinking was [points to a plastic gorilla that David is holding], was to make it look like it has like fur." During the various times that they worked on painting their sloth, they consistently checked to make sure that their gorilla resembled a sloth. They seemed to struggle with the ability to think about their gorilla in an abstract way (Schwarz et al., 2009). They could have simply said their gorilla was a sloth and not spent the time and effort making it resemble a sloth.

This group tried to make their biome appear as a replica, but they also attempted to replicate movements of organisms within the biome (Grosslight et al. 1991; Treagust et al., 2002). They desired to make things move as a way to show the fluctuations that were

occurring within their populations based on what happened during data collection. In all of their model construction they sought to have their model be a visual representation of what they had found within their data. They attempted to link the pieces of paper in the cup to the numbers of organisms within their box by using ratios.

Group B

Group B's modeling show that they understood that models can serve more than one purpose. Their model was a visual replica of their biome and a place to put their jellybeans. Since Group B viewed their model as a replica, they decided to bring in objects that would help their model look like a rainforest biome (Grosslight et al. 1991; Treagust et al., 2002). One specific way that Group B attempted to replicate their biome was when Penelope procured sod from her yard as the base of the forest within their box. While it had no connection to the rainforest, she said that they were using sod "to represent the grass." No other member in her group redirected her thinking about what plants were in the rainforest. The lack of constructive conversations addressing incorrect or misunderstood information kept the group from furthering their scientific understandings, both with content and with their model (Bruffee, 1999; Driver et al., 1994; Oliveira & Sadler, 2008). The group also sought to make it rain. They put round holes in the lid of their box and took Styrofoam cups and poked holes in the bottom so that water could drip out. Their final attempt to make their model appear like a rainforest also included their lid. Penelope suggested that on the lid they poke "little dots on the top so light could come through…. We need light to come in." This statement suggested that the light coming through the lid should only come from the top of the box like the sun

filtering through the treetops in the rainforest. The first purpose of their model was to provide a visual representation of the rainforest. Their second purpose was tied to their first. Their decision to create a box with plants, grass, rain, and filtered light was to provide a place for their cups of jellybeans to sit. In essence, their data (jellybeans) had no connection to the model they created.

During multiple prior activities that had students interacting and creating a variety of models, we did not utilize models that appeared like the objects they represented. The ideas that models should appear as replica is something that must be ingrained from prior science experience. It was also surprising that students had difficulties collecting data from their model, because data collection occurred during multiple activities throughout the school year. As both groups worked on building their models, however, it became apparent that they lacked the understanding that data can be gathered from a model.

What Came First?

While modeling, both groups had difficulty understanding that the data they were to collect needed to come from their model. They appeared to lack understanding as to how models and data can be connected (Komis et al., 2007). While neither group collected data from their model, they both attempted to link the numbers in their data to their model. It often appeared as though their data were influencing their model construction due to their data collection occurring simultaneously or prior to model construction.

Group A talked frequently of ratios between how many pieces of paper were in their cup to how many animals were in their box. The discussion of connecting their

model to their data seems to show that students were experiencing a cognitive wobble as they attempted to reconcile what they understand a model to be and their ability to collect data from their model.

Group B also struggled to understand what it meant to collect data from their model. They were able to glean information from the internet about the different populations, but that gathered data had no connection to their model. They first started by identifying population amounts. The population numbers were then converted into ratios for each jellybean in the cup. This same conversation occurred for their cocoa beans and their tigers. They continually tried to reconcile the numbers they had found online to the number of jellybeans that were in the bag.

As both groups worked, they appeared to rely on the data they collected to influence how their model would appear. Even though they all had prior experience collecting data from a model and then representing it mathematically they had difficulty transferring that prior knowledge. Both groups managed a mathematical representation of their data, but only David was able to articulate that a line graph would be most appropriate because it showed the change in populations over the years. Group B, apparently unsure of which mathematical representation was most appropriate, ended up utilizing both bar and line graphs. Both groups' graphs needed refinement. The ability to generate graphs from data was something that they had been taught in math and then those skills were reinforced in science. Yet, when given the opportunity to represent their own data, they struggled to create a complete and accurate graphical representation of their data that was gathered from the model they developed.

Concerning Research Question 2 (revelations of modeling from student conversations), I found that when students collaborated they focused on three things: prior experience, purpose of the model, and connection between model to data. The student's modeling conversations that were centered on prior experiences played a role in how they went about planning their model and identifying how they wanted to collect data. As they began discussing materials they needed, they tended to focus on materials that would make their model appear like a smaller version. The conversations around model construction centered on how the materials that were brought in could be arranged in such a way that the box appeared like their biome and that components also behaved in a similar manner. The final way that students were modeling revealed a struggle to understand the connection between the model and their data. Both groups' conversations flowed in such a way that the data were either collected simultaneously or prior to model construction.

Conclusion

This chapter reported my examination of the content of the students' conversations as they collaboratively attempted a modeling task. Group A worked in a semilinear manner. They identified their biome and the populations within their biome. They came up with ideas for their models and determined what supplies they would need for their model. During material acquisition Group A was divided in how their data and their model coincided. David focused on collecting the data using a plastic cup and small pieces of paper. The remaining members worked on building the model within a box. Members helped each other work on both tasks, but David took the lead on the data. As

David worked on the data, members attempted to make ratios for the number of items in their box connect to the number of pieces of paper in their cup. During their presentation the group demonstrated how their model worked and the data were left till the end.

Group B also worked in the same semilinear manner as Group A. They began by choosing a biome and their populations, then they asynchronously worked on the different parts of their model. Alexandra spent an inordinate amount of time on the computer shopping, gaining project ideas from Pinterest, and looking at memes. She was not the only one utilizing the computer. Evelynn worked on developing a digital rough draft of what their model should look like. As they figured out what their model would look like, they also decided what items they needed. After they assigned materials to bring in, Penelope worked to create graphs of the populations they had found on the internet. After they graphed their populations, they worked on making their model. Members in Group B made alterations to their model without consulting the remaining group members. These changes were rarely planned, and executions were rushed through. When this group presented the first time, they added and removed jellybeans, but subsequent presentations the jellybeans were added at random, and they made little connection with why there were jellybeans. While their model creation stories were different, there were some similarities as to how the groups used modeling.

While modeling, Group A and Group B both referenced prior experiences. Group A used an activity from the current school year, while B used an activity from a prior school year. Both groups sought to make their model look like the rainforest. Group B made sure they had tropical plants to represent the trees, rain falling from the sky, and

filtered light entering their box from an accurate direction. Group A tried to make the parts of their model similar in appearance and movement to the objects they represented. Both groups also struggled to understand that data can come from a model. Group A collected data as they built their model, while Group B obtained population numbers from the internet and called it data before they even knew what their model was going to look like.

This research has provided an opportunity to get an insider's perspective as to what students discuss as they collaborate on a modeling task and how students utilize modeling. The next chapter will discuss these findings, possible implications for educators, and possible future research opportunities.

CHAPTER 5

DISCUSSION, IMPLICATIONS FOR TEACHERS, AND POSSIBILITIES FOR FUTURE RESEARCH

Introduction

The research contained in this study is important for several reasons. First, it is important for my own professional development in my chosen career. Second, findings from this research could aid other educators as they guide students on their modeling journey. Finally, this study provides areas for continued research on modeling in middle school and possibly other grades. It is important to provide a reminder of the limitations for this research. This research was conducted with a small number of students divided into two groups. While the findings are valuable for educators and researchers, it must be acknowledged that with few participants the results may not be generalizable in other settings. Educators may identify ideas that could be transferred into their own practice.

Based on the analyzed student conversations, four main points of interest were identified:

1. Students' personal understandings about models played a critical role in the development and construction of their model.
2. Prior experiences with models were evident in the ways students talked about and developed their models.

3. Incongruent views of model development and data acquisition were apparent throughout model development.
4. Lack of interpersonal skills limited advantageous participation among students.

This final chapter will discuss two main findings from this research and will be compared to studies that were focused on modeling. From these conclusions, implications for educators and possibilities for future research will be identified.

Discussion

Based on collected and analyzed data, I identified two central findings:

1. Personal understanding of models influenced the participants' modeling experience.
2. The lack of interpersonal skills limited the continual development of their model.

Each student, from warm-up to presentation, had varying ideas of modeling and how things should be done. As students worked on their models it became evident that a student's personal understanding limited his or her ability to develop a model that could be used to collect data. David's (Group A) more complex understanding of models (Bailer-Jones, 1999; Passmore & Stewart, 2002; Shen, Chang, & Namdar, 2014; Treagust et al., 2002) was evident in his discussion with the group. While he sought to create something more abstract (Schwarz et al., 2009), the remainder of Group A and all of Group B desired to construct a replica of their biome (Grosslight et al., 1991; Treagust et al., 2002). Continuing to draw on his prior knowledge David attempted to steer members away from building a replica of their biome. No student in Group B tried to deviate from

the plan that their model resemble their biome. Due to the majority of members equating models to tiny copies, their material acquisition focused on items that bore resemblance to their chosen biome.

The only verbalized prior experience in Group A was David's mention of beans from the classroom population sampling activity. His understanding of the population sampling activity directly influenced the data component of their model. He adapted procedures and methods to fit within his understanding of the current modeling activity. Even though the remainder of the group did not discuss any prior experience, their frequent mention of construction and their desire to replicate the behavior and appearance of organisms and their biome seemed to show that their unidentified prior experience centered on physical models (Gilbert, 2004; Harrison & Treagust, 2000; Ornek, 2008).

Personal understandings of models due to prior experiences in science played a large role in the development of Group B's model. They relied on an activity done by two participants in a prior grade. They recalled replicating earth's crust with graham crackers. Their material acquisition was influenced by prior experience and their understanding of what should be included in a model, so they believed items needed to be edible.

In addition to students' personal understandings of models that they brought with them to science, they also drew on procedural experiences within the classroom. The utilization of plastic cups as a containment vessel within each model was an interesting addition. During the school year plastic cups were frequently used to transport or contain small materials for a variety of classroom activities, including modeling. As both groups

worked neither provided any indication as to why they used cups. Possibly, the use of cups in their models was due to experiences in prior science activities and models.

Not only did students' personal understandings of models aid in their model development, their understanding of mathematical concepts influenced the way in which they conversed about their data. Common core math standards for seventh grade contain four main areas. The first main area is centered on ratios and proportions (Common Core Standards Initiative, 2019). Participants in both groups clearly used their understandings of ratios in an attempt to make sense of their data. Because both groups constructed models that were replicas (Grosslight et al., 1991; Treagust et al., 2002) and were seen as separate from their data collection. They employed ratios to connect the two (Komis et al., 2007).

Based on the data gathered, students apparently relied on their understanding of various concepts to develop their model. Students channeled their understandings of prior experiences as they generated ideas and constructed their model. If students are to use their personal understandings to further group learning, they need to do more than work together. They need to be able to draw on their understandings and have the interpersonal skills necessary to effectively share ideas, identify concerns, and build on each other's knowledge (Driver et al., 1994). This ability to work together in order to build up knowledge leads into the other finding: A lack of interpersonal skills limited the continual development of their model.

For students to collaborate effectively they need to be able to ask questions, have discussions, and offer constructive opinions (Bruffee, 1999). The inability to have

positive interaction hinders the progression of group learning and understanding (Oliveira & Sadler, 2008) and limits refinement of their model. Students will also frequently accept the first idea instead of generating several ideas and picking one (Linn & Burbules, 1993). Oğuz (2007) suggested that model construction provides a way for students to build on their learning by reconstructing their models as new information is learned. In order for new information to be integrated within the group's understanding, there has to be that challenge for greater depth in explanations (Oliveira & Sadler, 2008). Without these in-depth challenging conversations, there is little new information for students to construct additional knowledge. As Bruffee (1999) described "knowledge is a consensus" (p. 3), and for there to be a consensus, there has to be open communication and positive discussions between all members within a group.

While each group worked on their modeling task, their lack of interpersonal skills impacted their modeling. Instead of partaking in an intellectually challenging conversation, a participant would quickly change topics or everyone would just stop talking. Linn and Burbles (1993) describe two outcomes of students group interactions. Students either utilize "the model of everyday discourse and remain silent about disagreements or they can assert ideas with authority" (Linn & Burbles, 1993, p. 96). David's attempts to explain his alternative understanding of modeling was continually met with indifference. They were unwilling to listen and build on his understandings to further the collective group understanding (Oliveira & Sadler, 2008). This behavior aligns with Linn and Burbles' (1993) group response when students remain silent about disagreements. Instead of using David's ideas to generate new ideas, the group remained

silent and ignored his statements or they changed the subject to something drastically different. Group B participants struggled for control of the group. Participants sporadically ignored select individuals when delegating tasks or discussing ideas for their model. They would grab things out of each other's hands, shush each other, and argue over a variety of things. This behavior aligns with Linn and Burbles (1993) second unhelpful group behavior, "asserting ideas with authority" (p. 96). Alexandra and Penelope continually stated ideas that they felt were the best, and there was no room for discussion. Disagreements about their model turned into bickering and one person refusing to work while the rest worked. The disagreement period tended to be short, but it severely limited the generation of new ideas based on older ideas. The inability of this group to have a constructive conversation limited their ability to create a model collectively. Their modeling ideas were limited to a few members, and there was no option for a discussion for possible refinement.

The inability of participants in each group to communicate effectively with each other limited the continual development or refinement of their model. They seemingly lacked the skills to listen actively to each other and to have a discussion based on knowledge rather than emotional response. These emotional responses limited any group reflection on their model. Without the ability to collectively reflect on their model and discuss ways of refinement their model creation ended. If they had the skills necessary to intellectually challenge each other, they possibly could have developed a more sophisticated model (Oliveira & Sadler, 2008). It would have been interesting to know what they could have done with their models had they all been willing to listen to each

other, work through confusion and misunderstanding, and offer differing ideas and opinions.

Implications for Teachers

In this project, students relied on their personal understandings in the development of their model, and their inability to work effectively together limited their ability to reflect and refine their models as necessary. Because students relied on their personal understandings, teachers need to be aware of their understandings in order to provide effective modeling instruction. The modeling instruction should incorporate a variety of models, as well as time to reflect on those models and their purposes. They need to discuss ideas for refinement (Grosslight et al. 1991). Teachers need to be aware of the *Frameworks* (NRC, 2012) and what it suggests that students should be able to do and understand by the time they graduate in relation to models and modeling. Elementary and middle grades modeling instruction in science must be viewed as a steppingstone to aid student's personal understanding of models and modeling, as they move onto high school.

Middle school teachers must incorporate modeling activities into their classroom in such a way that students can build on their prior understanding of modeling (Cheng et al., 2017). If students are to build on their prior understanding, teachers must aid students in identifying their prior understandings centered on models and modeling. Identification of understandings could provide a starting point for teachers to help students develop their understanding by the use of scaffolded modeling activities. Cheng et al. (2017) found that using a scaffolded modeling curriculum increased the sophistication of the

students' models. Knowing that scaffolding is beneficial for students, teachers can meet students where they are conceptually and make progress from there. A possible way to scaffold instruction within a classroom is to group students who have similar understandings of models, then provide differentiated modeling activities within those smaller groups. The differentiated activities could provide a semi-individualized scaffolded instruction centered on modeling, so that all students are provided with appropriate activities for their conceptual level. This approach would ensure that students have an opportunity to grow in their understanding of modeling.

Scaffolding is not the only technique to help students progress in their modeling understanding. Pierson et al. (2017) found that, if students were to have mature conceptions of models, they needed to utilize a variety of models within the classroom. This research found that as students utilized a variety of models they were directly influenced by those prior experiences. They used their experiences as references to aid their procedure development and material acquisition. Because students were specific in referencing prior experiences it is imperative that teachers provide students multiple experiences with a variety of models and the ability to scaffold modeling instruction and experiences. These experiences should not consist of looking at models but having opportunities to engage actively with models by making suggestions for refinement, collecting data from various types of models, and identifying what models are appropriate for various situations (Driver et al., 1994). Providing opportunities for students to interact with models gives students the foundation to construct their knowledge. Educators need to be purposeful in how they design and implement

scaffolded activities and how they expose students to a variety of models. Throughout the school year I purposefully had my students interact with activities of model construction and collecting data from a model. It was apparent in the data that just having students interact with those various models throughout the year was not sufficient for students to understand how to construct a model and collect data from it. Students need purposeful scaffolded instruction in both model construction and data collection from a variety of models to help progress their modeling abilities.

While this study occurred at a middle school the influence elementary teachers have on students' scientific understandings should be acknowledged. With the adoption of the *Frameworks* students at all levels need to be developing and using models. Laying the foundation for effective model development begins at the elementary school level. Knowing my own naïve conceptions of modeling before this study leads me to believe that many other teachers share those same views. Elementary school teachers may desire focused professional development on models and modeling. This professional development could assist elementary teachers in developing and implementing lessons that utilize a variety of models. These lessons could also incorporate activities that help students develop an understanding of how and why models are created. Laying these foundational skills and understandings at the elementary level provide opportunities for their future teachers to build on student's prior knowledge and understanding. Additionally, some middle school science teachers may desire professional development on models and modeling in order to effectively incorporate into their instruction.

Students' confusion as they developed their model about where the data originates from was intriguing. Both groups viewed data as something separate from their model and that was influencing their model. Teachers need to be explicit in their instruction surrounding data collection. Providing multiple opportunities for students to interact with data sets, identifying where data originated from, and identification of effective ways to present data could provide a foundation for understanding the complexities. Special care needs to be taken when addressing the validity of data. Both groups appeared to have no qualms as they altered data in an attempt to reduce confusion or to avoid conflict. Teachers need to ensure that students understand that errors in data collection can compromise the results and render their experiments invalid. Since students view models as correct answers (Schwarz et al., 2009), instruction needs to be clear. An attempt to achieve the perceived right outcome negates any conclusions drawn from error filled data collection.

Looking to the Future

The conclusions drawn in this study confirmed the prior findings that students struggle with model development (Chen & Lin, 2015; Grosslight et al., 1991; Pierson et al., 2017; Schwarz et al., 2009), making connections within their model (Komis et al., 2007; Treagust et al., 2002), revising their model (Schwarz & White, 2005), and identifying a variety of models (Grosslight et al., 1991; Lee et al., 2017). This final section will provide a list of future research opportunities based on my findings then discuss a few additional suggestions.

- The role of technology on group dynamics.

- The role of technology on model construction.
- The role of technology on the generation of modeling ideas.
- The quest for power and its impediment to model development.
- The use of unlimited versus limited technology devices on modeling.
- Boys and math and girls and model construction: gender roles in modeling.
- Grouping for homogenous modeling ideas versus heterogenous modeling ideas.
- The influence of group discussion instruction and norms on collaborative modeling.
- The influence of professional development on appropriate student grouping and those groups model development.

In addition to these ideas, this study revealed other opportunities for future research. Such as how personal understandings played a large role in students' modeling abilities. Future studies conducted within classrooms could explore the role that prior modeling experiences have on influencing students' current model development. Cheng et al. (2017) suggested that scaffolded curriculum is helpful in progressing student understanding but scaffolded curriculum may not be enough for students to have the academic skills necessary to develop their own model. Research could focus on students' incorporation of materials and methods from prior activities into their model and the reasoning to understand how to better use students' prior experiences for their benefit.

Komis et al. (2007) found that students struggled with making connections with different aspects of their model. Participants in this study also struggled to make the connection between their data and their model. Future research could seek to understand why students tend to separate data from their model and struggle to understand the connection between the two. Future studies could focus on why a disconnect exists between the model created and the data collected. Greater understanding is needed on students' thought processes as they determine where data should be collected from and what they think they should do with that data once it is collected.

The ability to collect mathematical data from a group-generated model required some form of number sense. In this study several students repeatedly struggled with basic number sense. The lack of number sense was evident as students attempted to determine the necessary number of jellybeans or attempted to ascertain the best value for items purchased online. The lack of understanding numerical qualities could provide insight as to why both groups struggled with data collection.

Participants in both groups mentioned their lack of perceived creativity on their ability to develop a good model. Examining a student's view of their personal beliefs of their creativite ability and how it influences their modeling and their ability to collaborate within their group could provide insight in the role of creativity in modeling.

Because the *Framework* discussed modeling in a scaffolded manner with each grade band, there needs to be a greater understanding of how models are being introduced in elementary school. If researchers can identify gaps or misconceptions at the

elementary school level, researchers could identify ways to better support elementary educators as they implement modeling within their classrooms.

In doing educational research one must be aware that teaching has an ebb and flow. With this flow teachers are continually attempting to identify ways to enrich and further their classroom instruction. Knowing this, future research avenues should focus on what would be the most beneficial in supporting educators in the long term as they help students further their modeling skills.

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APPENDIX A

CLASSIFYING GROCERIES

Part 1

Today you get to practice being taxonomists. You will create a classification model for groceries by placing the items into different groups based on their common characteristics. Create your classification model by completing the following

1. You must create AT LEAST four different classification groups. You may have more. You must name each group and under the group name, list the common characteristics that objects in each group will share.
2. You must place each item in a group. No group can have only one item.
3. You must add at least three additional items to each group that you have created. These additions will share the characteristics of the items already listed in the group. They will be items that I do not have listed.

Part 2

Choose AT LEAST ONE of the following items to complete on the back of your paper. If you finish early, you may complete more than one item.

1. Write a paragraph EXPLAINING your classification model. Explain why you decided to group items the way you did.
2. Write a paragraph DEFENDING your classification model. What classification have you made that other taxonomists (your classmates) might not agree with? Have you classified an item in a group when it could be placed in a different group? Do you have an item in a group with items that have different characteristics? Write a defense for any classification that you have made that you think other taxonomists might disagree with.

Grocery List – You must use all 50 items

Juicy Juice 100% Juice Boxes	Dr. Pepper	Hershey's Chocolate Syrup	Cliff Chocolate Chip Granola Bars
Keebler Club Snack Crackers	Chocolate Honey Maid Graham Crackers	Kroger Brand Tortilla Chips	Cheddar Cheese Cracker Combos
Cheez-It Snack Mix	Jiff Peanut Butter	Kroger Brand Apple Juice	Chocolate Filled Pretzel Combos
Twix Chocolate Candy Bars	Hershey's Cholate Candy Bar with Almonds	Lays Potato Chips	Mott's Chewy Fruit Snacks
Orville Redenbacher Butter Popcorn	Sprite	Motts Apple Sauce	Quaker Instant Grits
Tomatoes	Nabisco Nilla Wafers	Grape Flavored Powerade	Quaker Apple Raisin Oatmeal
Smartfood White Cheddar Popcorn	Strawberries	Apples	V8 100% Fruit Juice
Kroger Brand Pancake Syrup	Kashi Chocolate and Almond Granola Bars	Quaker Brands Chocolate Covered Granola Bars	Nabisco Ritz Crackers
Kroger Brand Mixed Nuts	Kraft Sweet Honey BBQ Sauce	Strawberry Poptarts	Kroger Brand Mustard
Kroger Brand Almonds	Pizzeria Pretzel Combos	Rice Crispy Treats	Pringles Original Flavor
Little Debbie Swiss Cake Rolls	Little Debbie Oatmeal Cream Pies	Swiss Miss Hot Chocolate Mix	Smucker's Caramel Syrup
Pepperidge Farm Milano Chocolate Cookies	Red Grapes	Post Honey Bunches of Oats Cereal	Chocolate Covered Strawberries
Betty Crocker Cinnamon Muffin Mix	Kroger Brand Pretzels		

APPENDIX B

TEST: CLASSIFICATION

Information gathered from **https://www.sciencelearn.org.nz/resources/158-develop-a-classification-system** and 7th grade science teachers

S7L1. Obtain, evaluate, and communicate information to investigate the diversity of living organisms and how they can be compared scientifically.

a. Develop and defend a model that categorizes organisms based on common characteristics.

Today you will be a taxonomist!
When scientists classify organisms, they look at a variety of characteristics.

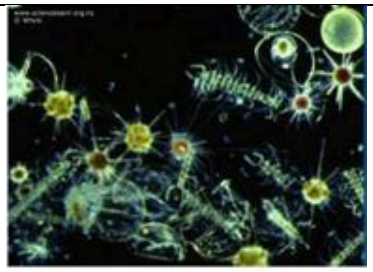
What to do:

Part 1:

1. **Group** the organisms shown on the image cards using the organism information provided into at least 3-5 categories. You must be able to defend your choices. (hint: start with broad categories)
2. **Name** each group.
3. **Record** the common characteristics of each group (the selection criteria used to decide which organism can be a member of that group).

Part 2:

1. **Further divide** the organisms from **Part 1** into a subcategory. (hint: more categories with fewer organisms in each…more things in common)
2. **Name** each subgroup.
3. **Record** the common characteristics of each subgroup (the selection criteria used to decide which organism can be a member of that subgroup).
4. **Write a paragraph** to a person that disagrees with your classification system. Explain/defend your classification choices of both groups/subgroups (why you did it the way you did) using the characteristics you chose as evidence.

 MANGROVE TREES	 SEAGRASS	 STALK-EYED MUD CRAB
 PHYTOPLANKTON	 DOLPHIN	 HUMAN
 GREEN LIPPED MUSSEL	 RED COD	 BLACK CORAL
 SOUTHERN ARROW SQUID	 BRYOZOAN COLONY	 COCKLES

SEA STAR

CRAB LARVA

SEAWEED

BLUE COD

CRAYFISH

ZOOID

Organism information

Organism	Basic information
Green lipped mussel	Lives in the intertidal zone, filter feeder, normally clumps together in groups, eaten by humans and sea stars.
Red cod	Normally found at depths of 100–300 metres, feeds on crabs, shrimps and small fish, adults about 40–70cm in length.
Seaweed	Type of algae, primary producer, grows in clusters with other seaweeds, provides shelter for small marine organisms.
Southern arrow squid	Mollusk, mostly nocturnal, feeds on crabs, small fish and sometimes other squid, eaten by birds and large fish, food source for humans.
Stalk-eyed mud crab	Habitat is low-tide zone, cannot survive out of the water for more than 8 hours. Popular food source for many fish, stingrays and seabirds.
Phytoplankton	Primary producers, microscopic, single-celled organisms, float freely in the ocean, eaten by zooplankton.
Dolphin	Vertebrate, mammal, lives in the water, feeds on fish.

Human	Vertebrate, mammal, lives on land, eats a number of marine animals.
Black coral	Branching coral, found in Fiordland, made up of colonies of identical organisms like sea anemones, feeds mostly on phytoplankton.
Blue cod	Marine fish, adults up to 60cm long, can live up to 150m below the surface, popular food for humans.
Crab larva	Crustacean, feeds on phytoplankton.
Zooid	Feeds on phytoplankton and dissolved plant matter in the water.
Bryozoan colony	Made up of hundreds or thousands of zooids.
Cockle	Mollusc, filter feeder, feeds on phytoplankton, lives in estuaries.
Sea star	Echinoderm, consumer, eats mussels.
Crayfish	Crustacean, breathes through gills, popular food for humans, feeds on crabs and small marine organisms.
Seagrass	Uses photosynthesis to make food; found in shallow salty water
Mangrove	Tropical shrub/small tree; grows in salt water

APPENDIX C

APPLICATION ASSESSMENT FOR ECOLOGY UNIT

Standard:
S7L4. Obtain, evaluate, and communicate information to examine the interdependence of organisms with one another and their environments.

Task:
Develop an interactive model that shows how a community of organisms change over time as resources and populations fluctuate.

To do:

1. Identify your biome:
2. Identify groups of organisms (can be plant, animal, fungus, or protist) you are interested in
3. Brainstorm with group, come up with an idea as to how to show fluctuations within your population based on resources or other organisms.
4. Fill out project proposal form
5. Once proposal form is approved begin development of your model.

Things to Remember:
-Information of your various populations (life span, location, resources needed, predators to avoid, prey animals- anything pertinent to provide evidence for your final product)
-Model- including evidence of different model variations- photos, videos, and/or physical representation.
-Data collected from model and then organized into a mathematical representation (starting populations, factor that causes change in population, ending populations, years that this population change occurred in)
-An explanation of what is happening in your model. (What population are you examining, factor that caused population change, and how does the population change and why)
-All drafts and notes from each step of your assessment – Keep all papers in your envelope in the classroom.

Project Proposal From

Group Member Names:
_____

Biome: _____

Populations: _____

What is the cause of the change in populations?

_____

_____

How will you model/show your change in populations?

_____

_____

_____

_____

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_____

What do you need to accomplish your task?

_____

_____

_____

_____

_____

_____

_____

_____

Project Rubric 1

	Got it (5)	Almost (3)	Getting Closer (1)	Not Quite (0)
Populations Identified with relevant information	Populations identified and information included (such as life span, location, resources needed, place in the ecosystem)	Populations identified some information included.	Populations or population identified but no information included.	Populations not identified and no information included.
Data Collection	Collected data is organized and easily understandable	Data is collected and semi-organized but is difficult to understand.	Data collected but it is not organized	No data included
Appropriate Mathematical Representation	Mathematical representation accurately represents the data (includes labels, title, number range…)	Mathematical representation adequately represents the data but is missing components.	Mathematical representation does not adequately represent the data.	No mathematical representation included
Written explanation of data	Explanation includes enough evidence that it explains what is going on in the model.	Explanation included but does not include adequate evidence.	Explanation provided but lacks evidence	No explanation given.
Interactive Model	Model shows the connections between populations in an environment	Model is complete but does not show connections between populations in an environment.	Model is incomplete	No model provided
Total in Rubric 1:				

Rubric 2

	Not Quite (0)	Got it (3)
Biome	Biome Not Identified	Biome Identified
Project Proposal	Project proposal not completed	Project proposal completed
Total in Rubric 2:		

Total in Rubric 1+ 2= _____

APPENDIX D

WARM-UP QUESTIONS

1. What do you think a model is?
2. What do you think a model is as it pertains to science?
3. Why do scientists use models?
4. How do scientists use models?
5. If you were to hear someone say “the modeling process” what do you think that means?

APPENDIX E

ANALYZED ANSWERS TO WARM-UP

Student Name	Question Answers	Codes	Themes	Assigned #
David	1. I think a model is showing the structure of something using materials.	Shows structure	Models are used to show or identify a variety of different things	3- explanatory because David mentions that models show relationships and understanding the connections between two items can mean that the model serves and explanatory purpose. Developing personal
	2. I think a model is, as it pertains to science, showing the relationships between elements, organisms, etc.	Shows relationships		
	3. Scientists use model to have a better understanding of something.	Understanding	Model is used to help personal understandings	
	4. Scientists use models to show their findings and look at someone else's findings.	Show findings	-communication purposes	
	5. If I heard someone say "the modeling process" I would think that means a process an organism goes through.	Process organism goes through		

Student Name	Question Answers	Codes	Themes	Assigned #
Corey	1. A replica of something	Replica	Copy	2- Placed in group two, models look the same, because she mentioned in almost every answer the
	2. An exact replica of something	Exact replica	Copy	
	3. To look at things they couldn't just pick up and look at like a cell.	Look at things – cell	Examine a copy of real thing	

	4. They use them to study things that they can't get.	Study	Used for another purpose – but used to help with difficult concepts which could mean exact copy just tactile or it could me something analogous to the difficult concept. Due to her pervious answers I am assuming that she means an exact copy, because her other others don't refer to anything analogous just replicas.	models are replicas and mentioned cells as a example of model and how they are used when you can't see the real thing.
	5. A process of scientists looking at a model of something.	Looking at a model		

Student Name	Question Answers	Codes	Themes	Assigned #
Isabella	1. Something that tries something on.	Tries something on	-	1- Assigned group one because student mentions different purposes of the model such as demonstrating and explaining. Both of those are using models in a teaching and explanatory fashion while she also mentions models as being copies.
	2. Something that recreates or looks the same as something.	Recreates/ look the same	Copy	
	3. To help explain what going on in a demonstration.	Explain	Models are used to help explain concepts in teaching settings such as demonstrations and presenting. Explain	
	4. When presenting something.	Presenting		
	5. I think it means to show something important.	Show I think It means to show something important.		

Student Name	Question Answers	Codes	Themes	Assigned #
Penelope	1. A model is a structure to show something/what it's going to be/normal shell	Show		2 She is placed in group because while she mentions

	2. Because it can explain more like to show DNA structure	Explain and show	Copy because she references DNA and show more like structure, so taking something difficult to see and making it larger	explaining her example is DNA to show structure. So while she mentions explanatory purposes she references a copy, which aligns to her other answer discussing how models look like the real thing and
	3. To show how it can look like if really small	Look like	Copy	
	4. They look at info and peace it together make models to show what it is	Piece together – show	Copy	
	5. To balicle (basically) model and how they build it…	Build		

Student Name	Question Answers	Codes	Themes	Assigned #
Liam	1. A model is a thing that shows what a product is.	Shows		1 Student is placed in group one because they show varying ideas about models from copies and identification. Even though they reference models as copies even then they are different various, one shows close up and one has the ability to be manipulated.
	2. A thing used to show close up pictures.	Show – close up	Copy	
	3. So they can determine what something is	Determine what something is	Explain / discover / models purpose	
	4. They use it by opening parts	Opening parts	Models come apart to show pieces – copy	
	5. A process of thinking being used.	Thinking		

Student Name	Question Answers	Codes	Themes	Assigned #
Wendy	1. A model is a replica of something or someone	Replica		1, student is assigned to group one because they mention different purposes for models such as
	2. A model that pertains to science is something like the human body or cells or organisms.	Something like the human body or cells	Copy – referencing a model is like the real things ex body, cells, or organisms.	

	3. Scientists use models to show people things like cells, DNA, organisms.	Show things like cells, dna organisms	Copy – referencing science concepts that frequently have an exact copy as a model	showing objects, teaching, or acquiring information.
	4. How scientists use model is they teach with them or to get information.	Teach or get information	Multiple uses	
	5. When I hear someone say "the modeling process" I think of how people make models or the process.	Make models		

Student Name	Question Answers	Codes	Themes	Assigned #
Evelynn	1. A display to show understanding	Show understanding		1, student was assigned as a one because she shows an understanding that all models are not the same but models can have different purposes.
	2. It can show the organization of something	Show organization	Multiple uses	
	3. To maybe show how things go together	Show how together	Multiple uses – all say show but show understanding, organization, and connections	
	4. Construct them to present	Construct to present	Multiple uses – models are also constructed to present	
	5. The process of making a model	Making a model		

Student Name	Question Answers	Codes	Themes	Assigned #
Alexandra	1. A physical example of an item	Physical example	Copy	1, student was assigned a one because they referenced several different uses of models. Models can be copies, the answer to a question, or a demonstration of an experiment.
	2. It shows you a physical image of what they are working on.	Physical image	Copy – 3-d replica	
	3. To have another way of showing that they're right.	Show they're right	Model is a correct answer	
	4. They use them as examples to show people how they're experiment works	How experiment works – example	Model isn't the experiment but shows how experiment works	

	5. I would think to hear it being said in a lab, I think it means a process of a physical thing.	Physical process		

APPENDIX F

DOCUMENT COMPARISON

Source	Group B	Group A
Project Proposal	Deforestation is mentioned as the reason for the decrease in populations of monkey and coco bean *their populations are not mentioned in relation to one another	Found what causes populations to go up and down within their environments. Organisms are connected sloths eat trees and jaguars eat sloths.
	3 cups with jellybeans, they will remove and replace beans to show an increase and decrease in populations These three cups will then be put into a replica habitat	For each organism they mention the popup, cutouts and paper for the data portion
	Needs included jellybeans and crafting items (cups, paper, scissors, glue, and markers)	Their needs included crafting items (glue, scissors, paper, cotton balls etc.)
Rough Draft	-digital drawing of what their box would look like	-Listed out their organisms and what ate what -drew a box to show where items could
Data	-googled population information for each organism and looked for a variety of years for that information *no data was ever collected from their model	Wrote scenarios as to what environmental event. happened each year. Picked pieces of paper out of a cup. Multiplied that number by 3 to show the entire population not just the sample population
Graphs	-Bar and line graphs were created for each organism each colored a different color used numbers and years that were found online no even spacing -line graphs appeared as a v, lightning bolt, and downward line *no care was taken for data collection and the lack of care shows up in the graphing	-did not include the starting number of each species -graphed all three populations on one line graph -different symbols were used for each organism -dates were at the top of the graph instead of at the bottom no lined perimeter
Explanation	-did not include an explanation of their model	describe their model as hands on model works by moving animals - got their data from the cup-then explained their graph *model and data are described as two different
Model	Model was a cardboard box with grass and cups of jellybeans, lid had holes and cups for rain -sides of box had graphs (line and bar) and it had the organism info. Box also included how many organisms	Model was a cardboard box that had movable components this was talked about separately from their data which was the cup with different colored pieces of paper