THE VIRTUAL GORILLA IN A LIFE SCIENCE CURRICULUM: SCAFFOLDING STUDENTS' KNOWLEDGE CONSTRUCTION IN THE CONTEXT OF AN INQUIRY-BASED INVESTIGATION

by

Rebecca Koopman

(under the direction of Dr. David F. Jackson)

ABSTRACT

This study investigated an inquiry approach to teaching and learning about biological themes and the nature of science in a 7th grade life science classroom, with supportive emergent technology. The purpose of the inquiry-based curriculum is to provide the framework for teachers to enable students' conceptual knowledge of animal morphology, physiology, and behavior that served to construct understanding of fundamental themes, such as the relationship of structure to function, and natural selection, while integrating standards-based process skills. A mixed methodology approach was utilized to structure an appropriate research design based on constructivism. Extensive field notes provided direct support for developing authentic naturalistic inquiry, leading to specific descriptions of teacher scaffolding and modeling, students' inquiry learning processes, and the role of technology in inquiry-based teaching and learning. Students' learning patterns are further supported by analysis of assessment products.

Key words: nature of science, inquiry-based teaching, biological themes

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BACKGROUND

Blending inquiry, technology and biology

The goals of science education are to improve student knowledge of scientific process skills as an avenue leading to a more complete understanding of scientific content. Klymkowsky refers to a bioliterate person as one who holds a "working knowledge of scientific method and practice" (Klymkowsky, Garvin-Doxas, Zeilik, 2003, p. 156). "Bioliteracy" as a concept in science education provides a term to describe not only procedural learning of terms and techniques, but the integration of a conceptual understanding of biological principles into a working knowledge of how scientists conduct investigations in order to obtain valid data and develop logical inferences. Even more importantly, the themes of biology hold profound relevance to personal issues and those of the global community. "While the realms of physics and astronomy appeal to our intangible sense of wonder, we are more directly aware of issues related to life, death, sickness, and health. It does not follow, however, that the general public's understanding of even the most fundamental principles of biology is better than its understanding of physical principles" (Klymkowsky, et. al, 2003, p. 156).

Inquiry defined by the *National Science Education Standards* (*NSES*) includes the "diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (NSES, retrieved fr. http://www.nap.edu/readingroom/books/nses/2.html#lsap). A wide range of activities are encompassed within this definition, including both oral and written communications by students. These "ways" in which scientists study the world are individually unique, yet still remain grounded by constructivist theory, implying that individuals create, or build, their own mental conceptual understanding based on their learning and experiences. It follows that active learning process are required for students of science to learn the abilities and thought patterns that are utilized to build authentic knowledge.

Often, scientists refer to their education as “training,” because it implies a rigorous active experience that develops the skills needed to think “like a scientist.” Science relies on the collection of rich data, but the process of data collection is only the beginning. Knowledge of biological processes and themes requires acquisition of both detailed facts integrated with an understanding of the complex interactions that interrelate biology concepts. Students of science hopefully acquire an understanding of this constantly changing body of knowledge, and realize that scientific theories have undergone intense scrutiny, extensive evaluation by individuals, and may be withdrawn when not supported with evidence.

Since there is no precise operational definition of inquiry, I chose to include a definition more pertinent to this study: “an educational investigation into an environment-virtual or real-in which the learner makes discoveries and draws conclusions” (Kuhn, Black, Keselman, & Kaplan, 2000, pp.496-497). As a definition of inquiry, the inclusion of the environment and the learner having a synergistic relationship within the context of the cognitive situational investigation is a significant element.

The National Science Foundation (NSF) promotes reflective inquiry assisted by computer-based investigation environments for K-12 classrooms. One of these projects is termed the Supportive Inquiry-Based Learning Environments, SIBLE, and is aimed at helping students acquire skills for reflective inquiry with a software tool called the *Progress Portfolio*. (Gomez, 2005, retrieved from http://serc.carleton.edu/resources/517.html). “It allows students to document and reflect on their work using an integrated suite of screen capture, annotation, organization, and presentation tools. In addition, teachers can use the *Progress Portfolio* to guide students in their work through the design of prompts and templates that encourage students to think about key issues as they work. This tool provides support for students to record data, annotate and make notes, and organize their work. Blending this type of supportive software with an investigation environment that emphasizes evidence, analysis and explanations provides a framework for students to think and verbalize about the process of inquiry itself. The supportive tools used by the teacher facilitate reflection on inquiry, and allows for teachers to evaluate and assess authentic student knowledge construction.

The existence of a multitude of technology-assisted learning environments provides evidence that technology is increasing in popularity as a tool for teachers and students to develop student-focused learning. By discovering how science knowledge is constructed in a typical learning environment with an experienced teacher, as opposed to an unrealistic learning environment supported with advanced technology and lacking teacher-developed curriculum, this investigation contributes to a significant need in the educational community. What the educational community is lacking, and what is increasingly needed by teachers, is evidence for successful integration of technology tools for specific learning objectives combined with descriptive reporting of how students' thought patterns are following along the inquiry framework. In other words, before teachers invest the time and energy in developing an inquiry-based curriculum that introduces new technologies, they need background knowledge of inquiry as a process skill, and a "snapshot" of students' active learning processes in a flexible and realistic format. If teachers believe in the value of inquiry and understand classroom learning environments that are inquiry-based, it will facilitate the use of inquiry for students' specific content learning objectives. Beliefs about the "viability of pursuing the teaching of "science for all," (i.e., whether all children can learn science) and the nature of instruction appropriate for students of various backgrounds, abilities, and interests" have a powerful influence on teaching practice (Anderson, 2001, p. 8).

Researchers use different terms to describe inquiry-related processes that others apparently would label with "inquiry" (Anderson, 2002, p. 3). Often, the term "student-designed investigation" is used in the context of inquiry learning. Anderson established a description of teacher roles, student roles, and student work along the continuum of traditional to reformed pedagogy in science instruction. The predominant activities in the "new orientation," or inquiry-oriented, learning processes occur when the student: "directs their own learning, designs and directs [their] own tasks, emphasizes reasoning, [reads and writes] for meaning, solves problems, builds from existing cognitive structures, and explains complex problems" (Anderson, 2002, p. 5). Initially, study of student-driven learning was entirely focused on detailing the students' activity and behaviors. Ultimately, the implementation of inquiry in the classroom is fundamentally connected to the dynamic interaction of the student, teacher, and learning environment that is driven by teacher beliefs and values. Therefore, this investigation includes an analysis of the critical component of teacher ideology and ideas regarding teacher modeling of scientific inquiry.

Various technology-based learning environments have provided evidence for achievement of science process skill objectives, and supported this investigation framework for an "inquiry into inquiry." The development of students' cognitive skills during the inquiry process is examined in-depth with the concept of "system thinking skills," or students' cognitive methods of knowledge construction for earth science (Assaraf & Orion, 2005). Students were found to have made meaningful progress in the development of "system thinking skills" and onethird of them reached the "highest level of system thinking" in their investigation into the hydro cycle. Researchers also asked about the relationship between the cognitive components of system thinking. By examining the synthesis of data regarding the variables that were subject to students' analyses, investigators were able to discern interrelationships "among the various factors that influenced students' ability to deal with the hydro cycle as a system" (Assaraf, et. al, 2005, p. 525). Geographical information systems (GIS) have also received attention as a support upon which to develop inquiry learning for environmental science. Audet and Abegg (1998) compared problem-solving behaviors between experts and novices with a program called *ArcView*. Problem-solving strategies described during reflective think-aloud sessions were evaluated through naturalistic research methods and were analyzed for occurrence of thematic elements. Initially, the emergent technology was used by expert geographical systems analysts before its widespread educational application for supporting student investigations. The Virtual Solar System (Barab, Hay, Squire, Barnett, Schmidt, 2000) is a curriculum that utilizes 3-D modeling tools to support an environment for the study of physical and space phenomena. The learning that takes place with this emergent technology is established by environments that "immerse students within contexts that challenge, ground, and ultimately, extend their understandings" (Barab, et. al, 2000, p. 9). Students attempt to create models of astronomy processes and develop their own research projects.

Behavior Matters is a curriculum designed to integrate smaller components focused on content objectives of animal behavior and ethology. The *Animal Landlord* software scaffolds students' analysis of complex animal behavior and facilitates comparison and contrast of video-captured behavior (Golan, Kyza, Reiser, Edelson, 2002). Findings include the assertion that software is supporting the engagement of students in productive discussion of significant "conceptual and strategic issues, such as the precise definitions for behaviors, the significance of the observed behaviors and the need for careful descriptions and interpretations of the observed behaviors" (Golan, et. al, 2002, p. 1).

The Virtual Gorilla and biological themes

The Virtual Gorilla Modeling Project (Hay, Crozier, & Barnett, 2000) began as a means for creating inquiry into the world of gorilla behavior and primatology using an emergent technology based on flight simulation software. As a unique example of both educational technology and "inquiry-based learning," the "Virtual Gorilla" (VG) curriculum provided an opportunity for this research study to investigate components of the inquiry spectrum. This investigation established an analogy between my inquiry and the guided inquiry of students in the 7th grade classroom. As I sought research questions and methodologies that would reveal and clarify students' thought processes, students investigated questions and began performing critical thinking and reasoning about appropriate means for collecting data, analyzing, interpreting and drawing conclusions from their research. The subject of biology encompasses a massive infrastructure of terms, themes, processes, patterns, and methodologies. Central to the theme of biology is the understanding of diversity in organisms and the processes of natural selection. Emergent technologies for the study of biology seem to experience limitations based on the limitless variation and investigations that are relatively open-ended; in a sense, increasing knowledge of biology serves to generate more unanswered questions than answers. Study of gorilla morphology and behavior provided students with an engaging context to learning with technological and scientific tools. Zoo Atlanta is developing a project for visitors with experiential learning, in which one would enter a gorilla habitat as a juvenile gorilla and interact with members of the group. Inappropriate behavior, such as approaching a dominant animal too quickly or direct eye contact would result in species-typical aggressive responses from the other group members (Beck, 2001, p. 212).

Primatology research activities established hands-on involvement with a current subject of modern research, open the door for accommodating multidisciplinary curriculum objectives, such as systems biology, ecological and environmental science, classification and natural selection. Threats to mountain gorillas pose a significant problem for our society and present a real problem that will only be solved with a community-based solution. The map (Figure 1.1) depicts the current distribution of gorilla species in Africa.

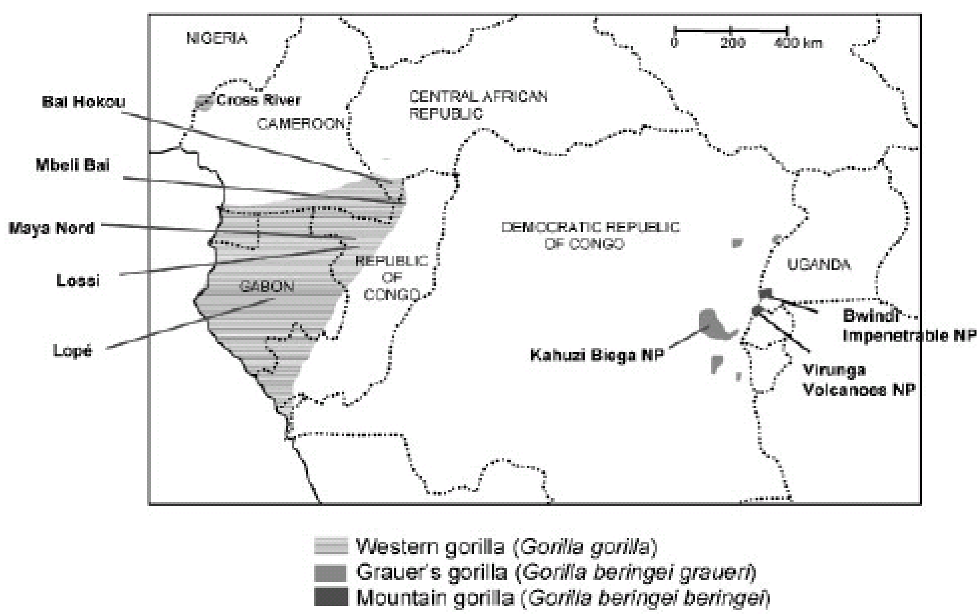

Fig. 1. Map of Africa indicating all the study sites discussed in this paper.

(map courtesy of Robbins, et. al 2004)

Figure 1.1 Current distribution of gorilla species in Africa

The county curriculum for 2004-2005 combined science process skills with content standards. In addition to exhibiting numerous science content and process skill standards, the VG Project emphasizes scientific themes that are critical to effective scientific research. The use of evidence for explanation, organization of research processes, and aligning research methodology with research goals are inherent in classroom activities. Most of the inquiry standards were addressed by VG curriculum activities. The standards alignment for the investigation included the learning objectives listed:

1. Use appropriate scientific tools and technologies to gather, analyze and interpret data
2. Question claims made without evidence or those based on small or biased samples
3. Communicate scientific procedures, instructions, and explanations
4. Design and conduct investigations using scientific method
5. Draw conclusions and/or design a new scientific investigation based on the results of a prior investigation
6. Compare body plans and internal structures of representative organisms which help them survive
7. Explain the scientific processes that result in organisms changing over time

Study of human origins and relationships between species provide a contextual basis for demonstrating problems addressed and examined by modern scientists. Conceptual understanding of organism diversity is the first content objective addressed by studying gorilla morphology, motion and behavior. Extending the concept of diversity to the theme of natural selection is enhanced with the use of gorilla and hominid skulls as evidence. "An accurate understanding of how scientists study the past by interpreting patterns in existing evidence, and by investigating processes which cause evolution, is a necessary prerequisite for understanding and appreciating the extensive empirical support for the fact that evolution has occurred" (Cooper, 2004, p. 152). Students need to learn biology as a web of conceptual layers that constantly interact. Findings drawn from discovered remains require explanation and logical reasoning that depends on fossil dating, fossil anthropology, and extensive reconstruction of evolutionary lineages (Lewin, 2003). The story of hominid origins is constructed by different disciplines, methods, evidence, and arguments. Knowledge of primatology and primate characteristics will undoubtedly contribute significantly to the ability to compare hominid species.

At Zoo Atlanta, the term “investigation” applied to the Virtual Gorilla was defined as “a comprehensive perspective focused on actively engaging learners in authentic scientific inquiry” (Hay, et. al, 2000, p. 23) and provided evidence for learners’ deep understanding of scientific principles and concepts as they asked questions, conducted investigations, and reflected on the research process. Key-frame animation is a technique that participants used to construct video of gorilla motion. This interface supports the learners through the process of animating gorilla behavior in a straightforward manner. “Based on observations, learners bend and position the “virtual gorilla” to the correct “key” positions that would make up a motion, such as from a sitting position to an upright position. For each key frame, learners worked on a time line and the software would interpolate the motion between the key frames, thus creating a smooth motion” (Hay, et. al, 2000, pp. 6-7). The learner must orient their procedures and tasks to the specific goal of creating the gorilla’s locomotion, in a performance-oriented environment where the student constructing a unique product.

RESEARCH DESIGN

Participants

Students

Nearly eighty 7th grade students who were enrolled in 4 classes at a suburban middle school and studied a unit on gorilla biology, behavior patterns, morphology, physiology of organisms, and fossils, participated in this study. The middle school population is about 3000 students enrolled in grades 6-8. Students performed inquiry-based learning activities in the context of a technology-assisted learning environment. The students' mean age was 12, and represents a slightly narrowed range of ability because students were in the 'gifted' track. The majority (~85%) of students was Caucasian, 9% of students were African-American and 5% students were Asian-American. The school is located near the metro-Atlanta area, in the largest school system in Georgia. The district is relatively diverse and incorporates approximately 6,000 new students each year into its schools. The middle school uses Zoo Atlanta for field trip activities. Students that qualified for free and reduced lunch at the school were estimated at 9% and 4%, respectively, suggesting a relatively middle class population.

Teachers

The classroom teacher held 4 years of classroom teaching experience of 7th grade life science and a master's degree in education. In addition to being a first year doctoral student at the state university, she participated in the professional development workshop held the previous summer to improve teaching of inquiry in the classroom with the "Virtual Gorilla" (Hay, et. al, 2000). The teacher has recently completed research papers on the nature of inquiry in the classroom and historical perspectives on science education, in addition to presenting current curriculum at the state science teachers' association annual conference. Her advising professor assisted with teaching some of the lessons in these units. The classroom teacher will henceforth be referred to as "CT," for classroom teacher.

A professor of science education served as a guest teacher during lessons in this unit involving the investigation into bones and skulls and the emergent technology. He lived and taught for 11 years in areas of Uganda and Kenya, before returning to the United States for completion of graduate study. His experience with the natural landscape, wildlife, archaeological discoveries, and current research of those regions provide a background for knowledge of biology and teaching practices. He will be referred to as "GT," for guest teacher.

Data collection

The methods utilized were chosen to generate a detailed and grounded qualitative analysis and included a qualitative report of participants' learning activities with descriptive field notes. The framework for investigation was centered around authentic reconstruction of student learning within a rich environment of inquiry and technological tools. The qualitative analysis was guided by systematic interpretation of students' learning activities, including extensive field notes, students' assessments as products of investigatory processes, student verbalizations in the classroom, students' interactions with other students, and interactions between the students and the classroom and guest teachers. The gorilla activities spanned the length of the school year, beginning with an introduction to scientific inquiry and several gorilla-themed curriculum activities, and completed at the end of the school year following the study of the human body. The timeline of inquiry-based curriculum activities provides a look at when these activities occurred during the school year, and the overall sequence of activities. (Figure 1.2)

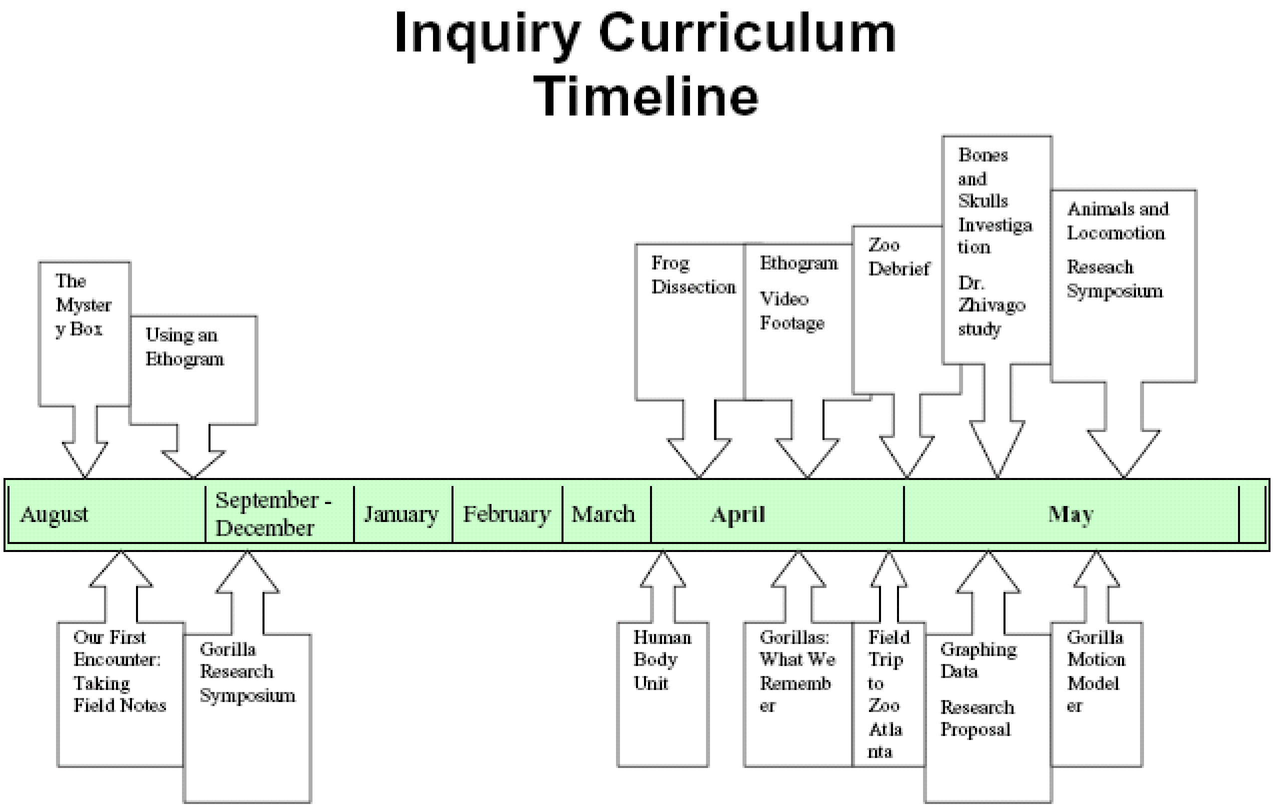

Figure 1.2 Timeline of inquiry curriculum activities

At the beginning of the school year, students completed an initial foray into scientific inquiry by investigating scientific processes and methods such as hypotheses, inferences, predictions, descriptions, and observations. They performed “The Mystery Box” activity (available at http://www.coe.uga.edu/science/projects/xrays/boxes.html), a lesson designed to focus students’ attention on cognitive processes scientists use to determine the unknown. Inside the box were unknown objects they sought to identify with only the sounds from the box and the feel of the objects as they rolled and slid within the box.

With the introduction to the nature of science, students were initially introduced to the study of gorilla behavior in a lesson called “Our First Encounter: Taking Field Notes.” Students were introduced to the terms “qualitative” and “quantitative” research to establish the concept of distinct methods based on the research question. This concept was reinforced by a lesson on learning to make ethogram notes as a means for transforming qualitative observations into static numbers. Students used an ethogram developed by a primatologist from the zoo (Table 3.4).

Students made observations of gorilla behavior from video footage taken from the zoo as part of their introduction to using ethograms. Based on their field note observations of a juvenile male gorilla and an adult male gorilla, students graphed both sets of data, and interpreted the different behavioral patterns. Finally, students participated in a "Gorilla Research Symposium," and investigated their own questions pertaining to gorilla biology. Students were encouraged to choose topics they wanted to learn about, and chose questions such as, "What is the life cycle of a gorilla?" They constructed *PowerPoint* presentations to develop their self-concepts as scientists who presented their results to family members and peers in the classroom. Immediately prior to this unit on gorilla biology and animal morphology, students completed a unit on the human body. They performed a frog dissection over a 2-day period, with 1 day for external anatomy and 1 day for internal anatomy. The students performed the dissection in groups of 3 or 4, chosen by the students. Each class period consisted of 16-20 students, which enhanced the use of collaborative group work.

This investigation examined how inquiry "works" for students' learning of scientific process skills used in biology. This study attempted to contribute to the research in this critical area of science education, and sought to provide significant discussion and collaboration for improving the objectivity and validity of the evaluation. I observed and depicted my observations with a focus on random representative samples. The observation sessions were required for authentic descriptive reporting and accurate accounts of student learning within the classroom environment. I produced rich description of the classroom learning environment that included student discourse, utterances, and teacher-student interactions. “Validity, meaningfulness, and insights generated from qualitative inquiry have more to do with the information richness of selected cases and the observational capacities of researcher” (Miles & Huberman, 1994, p. 212). Observation was required to characterize the true nature of a learning community, and characterized the development of the study and its inquiry into learning.

Data was collected from students’ work performed during the classroom observations and the field notes from those classroom sessions. My notes were taken initially with a “semi-structured observation protocol” and direct transcription. I was present for nine days of observation that included four separate class periods of 70 minutes each. Field note data was transcribed and coded within the original four domains. These transcripts were the source of the nodes discussed earlier. I derived evidence of students’ learning processes from field notes. In addition to the nodes, I made use of margin notes to pose questions resulting from each daily session. Later, analysis would determine whether these questions were relevant or meaningful pursuits for investigation during the remainder of the study. The field notes provided a basis for interview questions that focused on teacher beliefs about the VG curriculum in the biology classroom. Data analysis included further interpretation of the transcripts, review of students’ authentic assessments, triangulation with colleagues, and diagramming students’ thought patterns.

As an analytic inquiry investigation, evidence from field notes included student utterances, student-student interactions, teacher-student interactions, and teacher questions during lessons. This evidence revealed clues of students’ conceptual understanding of animal physiology and behavior patterns, procedural knowledge of scientific investigation, and transformative knowledge required for inquiry-based investigations. The activities analyzed during observation occurred in the following sequence (Table 1.1).

Table 1.1 Gorilla activities

Activity
Gorillas: What We Remember
Ethogram Video Footage
Field Trip to Zoo Atlanta
Zoo Debrief
Graphing Data in Excel Student Research Proposal
What can we learn from bones?
Dr. Zhivago's study What can we learn from skulls?
What can we learn from skulls?
Gorilla Motion Modeler
Research Presentations

Student assessments comprised an essential component of this investigation. Authentic performance assessments provided a more accurate picture of knowledge construction and transformative learning than multiple choice exams would have provided. The systematic collection and interpretation of students' research proposals, field notebooks, reflective writing, ethogram graph data, and *PowerPoint* presentations led to construction of the flow charts for students' cognitive activities during the inquiry investigation. The assessments were initially coded for evidence of data collection, analysis, communication, and inquiry-related processes. The inquiry process grounding my investigation inspired the naturalistic inquiry that developed larger conceptual nodes, derived from students' assessments and from classroom observation field notes. The nodes that I developed were more directly correlated with the research questions (see Table 1.2). Student assessments were used as evidence for answers to my initial research questions, as well as evidence of concepts or themes revealed in the nodes. Analytical inquiry of students' assessments related students' conceptual understanding to the components of the inquiry spectrum of the analysis framework. Display of students' skills in graphical format provided an additional method of evaluating the initial research question: "What are students learning about scientific inquiry?"

A growing concern of educational researchers is the validity and confidence in findings derived from qualitative data (Miles & Huberman, 1999). There is increasing discussion in the research community regarding the methods for addressing the issue of validity and the strategies for reinforcing researcher findings. The research strategies included to strengthen this study used triangulation, multiple methods, and multiple perspectives (Miles & Huberman, 1999). Data sources were also widely varied, and included evidence from both field notes and assessments.

Data analysis

Researchers who employ qualitative analysis and interpretation methods value their representation of theoretical phenomena as a "true telling of the story," a report of "how something is seen and reacted to, and thereby meaningfully constructed, within a given community" (Crotty, 1994, p. 64). As a researcher in science education, I had a keen awareness of its educational application and valid representation of inquiry-based learning in biology that guided the context and analytical focus of my research. A scholarly qualitative research study derives its focus from what one has learned and involves an ongoing dialogue with colleagues about particular questions of interest (Miles & Huberman, 1999). This study benefited from continuous review and reflection pertaining to methodology and emerging questions for additional investigation.

The method of naturalistic inquiry facilitated the posing of additional research questions and ideas regarding students' understanding of the transformative nature of inference and conceptual connections, and the importance of scaffolding research tasks, comparing data, students inferring relationships from data analysis, reflection, collaboration, communication, and teacher modeling of scientific thought processes.

A summary (Table 1.2) of the evidence that served as the basis for node construction was created.

Table 1.2 Node description and sources of evidence

Node	Evidence	Description
Teachers scaffold and model the processes of inquiry.	▪ Zoo Safari activity ▪ Students' field notebooks ▪ Students' research proposals ▪ Utterances between students ▪ My field notes ▪ Teacher/student interactions	Teachers initiate descriptions and observations to support the learning goal. Teachers ask questions, designs methods to investigate, and evaluates evidence to model inquiry processes.
Students construct conceptual knowledge of inquiry processes based on explicit cognition patterns of desired thought processes.	▪ Zoo Safari ▪ My field notes ▪ Students' field notebooks ▪ ethograms/graphs ▪ student/student utterances ▪ Dr. Zhivago, *PowerPoint*s, ethograms/graphs ▪ Teacher/student interactions research proposals	Students construct descriptions based on their observations. Students construct data comparisons and these comparisons lead to inferences. Students' data analysis drives the essential process of reflection, and forms the basis for communications.

My naturalistic inquiry into the cognitive components led me to integrate the multiple facets of inquiry and research among 7th grade life science students into an iterative, coherent, reliable and creative project with implications for the use of both technology and inquiry in science classrooms. Due to the nature of analytic inquiry, I expected to experience insights and interpretation during the data collection process. The process of “thinking up” (Bazeley & Richards, 2004) from nodes and reference to “sensitizing concepts” as nodes, or “red herrings” that represent rich fields of concepts for fishing into illustrates the importance of background knowledge to build upon observations and field notes.

The nodes resulted from both observations during the VG lesson activities and the theory of constructivist learning. A mixed methodology approach employed grounded theory of constructivism. “Hypothetical inferences may lead to rational and well-founded assertions which are both consistent with observed phenomena and with previous theoretical knowledge” (Kelle, 2005, p. 13). In order to design a strategy conducive to these types of inferences, I referred to several sampling methods related to inquiry and large sampling data sets. Opportunistic or emergent sampling (Miles & Huberman, 1994) allowed flexibility for the following of new leads during fieldwork and taking advantage of the unexpected. This sampling method relies on the unforeseen opportunities that occur after fieldwork is begun. Furthermore, the purposeful random sampling method (Miles & Huberman, 1994) was used to increase the credibility of results when the potential purposeful sample is larger than one can handle. Since there are no hard and fast rules for sample size in qualitative inquiry, credibility is related to systematic but truly random selection of reported cases. I utilized random selection of student responses to obtain a credible sampling.

Research questions

During the initial design phases of the study, I generated research questions that were of particular interest based on my conceptual knowledge of biology and the nature of science. The questions were organized around a central aim of the investigation: “What are students learning about scientific inquiry as a result of this curriculum using emergent technology and contextual investigation?" and included the concepts of data collection, data analysis, communicative processes of learning, and inquiry-related skills such as posing questions and reflecting on research. I investigated these initial research questions with methodical observation and systematic data analysis. I attempted to organize interpretation within the four concepts I had generated during the design phase of the study, and referred to these as "domains."

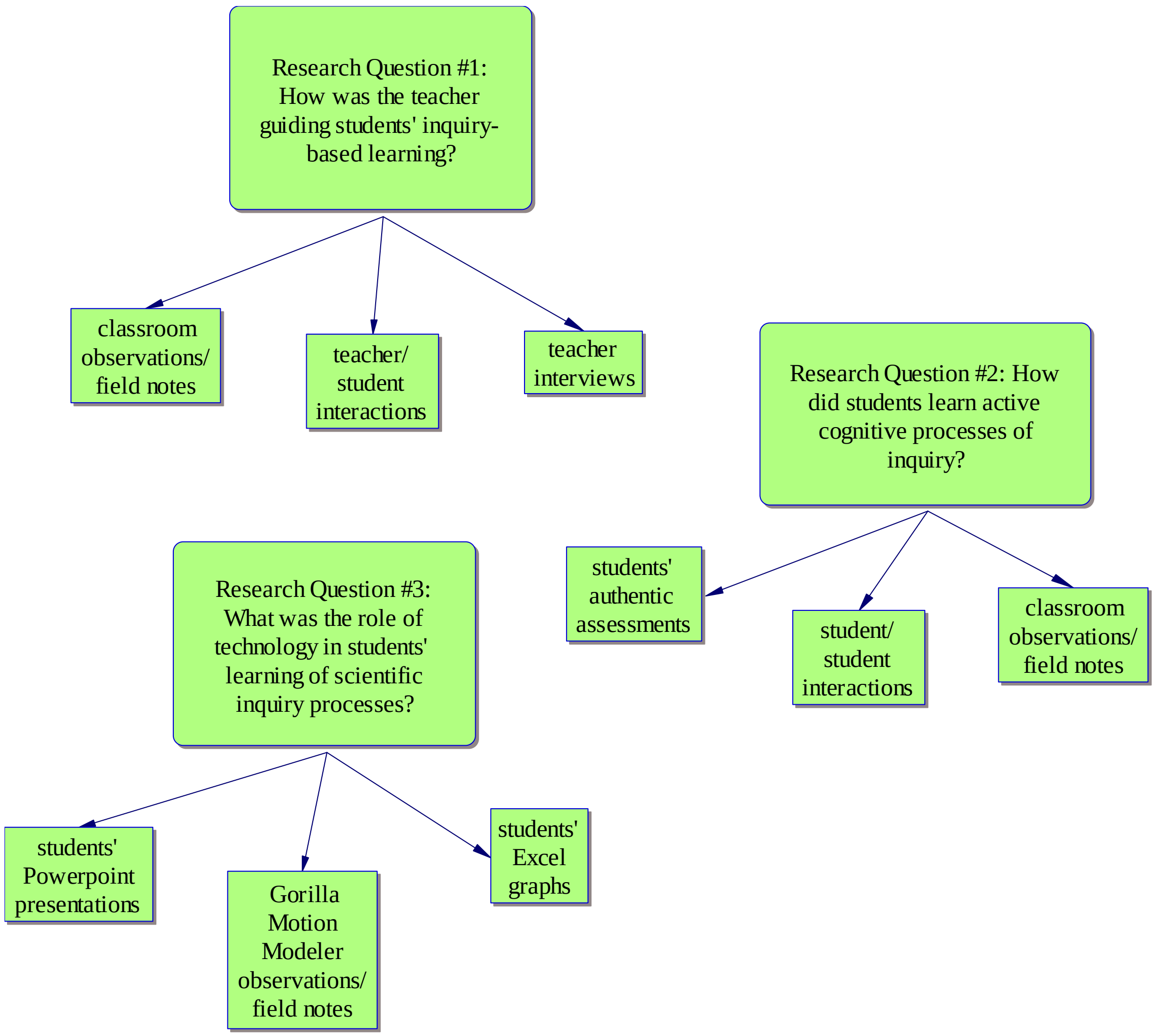

Figure 1.3 Guiding research questions

As I identified characteristic actions of teachers and students involved in active cognition, I began to paint a picture of how the teacher, students, and environment all contributes critical factors to the learning environment. I refined and focused my original research question into three questions for which I acquired supporting evidence. First, how was the teacher guiding students during the inquiry-based learning? Second, how did students learn active cognitive processes of inquiry? Finally, what was the role of technology in students' learning of scientific inquiry?

Reflecting on the research methodology for this project resulted in the interpretation of a research design for congruent, credible findings while also promoting insight to characterize students' learning of scientific inquiry. My interpretation was inherently biased by professional and educational influences, yet my awareness of my own conceptual constructs furthered my insight into a balance between subjectivity and objectivity. My observations provided an examination of how teacher pedagogy dictates the quality of students' interactions in the classroom. As a non-participant observer, my data collection consisted of both descriptive reporting activity as well as interpretation of data in the form of field notes and student assessments. In a constructivist nature, I blended my current ideas of using inquiry and technology in the classroom with what occurred during the investigation into the VG Project.

RESULTS

Teachers develop scaffolding of the learning goal

The second "phase" of the gorilla curriculum occurred at the end of the school year and related the new learning objectives about inquiry to the prior objectives related to using tools to gather data and comparing living organisms scientifically. The first activity reviewed students' knowledge of the nature of science, and was characterized with the title: "Gorillas: what we remember." As part of the constructivist learning cycle, students were "invited" to the gorilla world with vocalization recordings from a website (available at http://www.berggorilla.de/english/faq/dvers/hoeren.html). The initiation was intended to incite curiosity and focus students' attention. Students were asked to list nine topics in their field notebooks and fill in what they remembered from the beginning of the year. The technique served a dual purpose of formatively assessing students' conceptual knowledge, and driving the students' reflection and collaboration. The topics were: 1) making observations, 2) communication, 3) location, 4) diet, 5) daily habits, 6) classification, 7) habitat, 8) threats, and 9) other. The students' field notes revealed students' ideas of collecting data, analyzing data, communicating about data, and research designs for observing animal behavior. The learning environment was a simulated scientific conference, or "roundtable" discussion, as the teacher asked students to "stand up and share what you have learned." By situating students' reflective activities in the context of a scientific symposium, the teacher encouraged students to contribute meaningful feedback in the form of scientific commentary and discussion. Figure 1.4 illustrates how a typical inquiry-based activity could promote solving a research question, in this case the question was: "What behaviors do gorillas demonstrate at Zoo Atlanta?" The teacher supported students' progression from a simple question through a framework of multiple data acquisition and analysis steps, not all straightforward, and leading to gradual integration of self-evaluation through reflection and developing the ability to pose appropriate research questions, an indication of true inquiry-based learning.

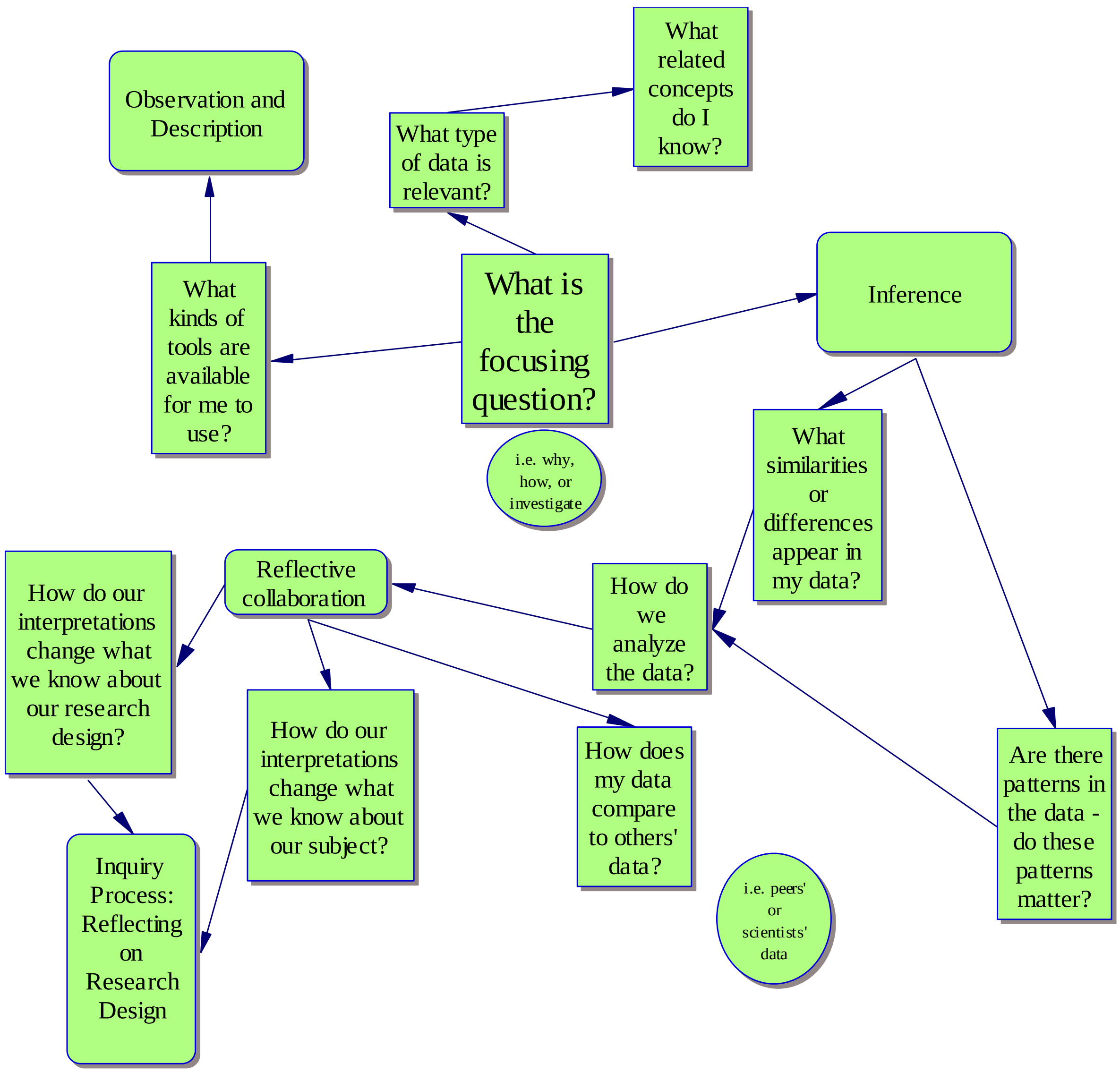

Figure 1.4 Cognition Framework for Scaffolding Student-driven Inquiry Investigations

The orientation of student learning was placed within a goal context; the gorilla investigation was investigating an interesting question about gorilla behavior. There was evidence of focus on a goal or problem in students' research proposals where they wrote about different types of gorilla behavior and observation strategies, field notebooks that served as a data repository and place for students to write notes and explanations essential for construction of scientific meanings, and teacher-students interactions that depicted a rich interface between the questions being asked and students' thinking strategies. The guiding force for scaffolding inquiry was the questions that required students to evaluate their thinking patterns in terms of solving the research question. The refocusing action of these questions was deliberate and conscientious, because the teacher was aware of students' tendency to lose focus of the overall goal, which is to align the data, analysis and interpretations with a search for knowledge that answers the research question. "I remember what my attention span was like at that age." Students need guidance and formative assessment throughout this process. Questions were articulate, pervasive and an integral component of the entire curriculum. The term "scaffolding" was consistent with the supportive yet challenging nature of this method of teaching, because students were provided the opportunity to design their own experiment, within the context of a supportive learning environment. Notice in the cognition framework how students had to examine their data and look for patterns, compare their data to others' data sets, and think critically about what their data might mean. Students' choices were subjected to constructive evaluation by an environment that supported meaningful comparisons with teachers' modeling of these processes and other students' thought processes.

After analyzing the data, the teacher used a performance assessment to make students responsible for a finished product that describes and makes conclusions about their investigation. The research proposal assignment enhanced reflection, as an assessment that guided a review of students' inquiry related procedures defined by learning objectives for students to construct their own knowledge of what techniques worked well for their research and which did not. For example, many students drew conclusions from the data obtained to infer characteristics of their gorilla, like it was an “active,” or a “tired” animal. Students also explained why the sampling time of 20 minutes was too short for valid data collection, and related that their data could not be trusted.

The use of a rubric constructed by the teacher on the day of the research proposal assignment meant the assessment was specifically tailored for learning objectives specific to inquiry processes that students had just experienced. Specific components (Table 3.1) of the research proposal rubric required data analysis, reflection on research design, inferring ideas from data, and designing research investigations.

Table 3.1 Inquiry criteria in research proposal rubric

Requirement	**Point value (out of 100)**
Explain WHY you chose your sampling time	10
Interpret your graph	10
Is your data representative/valid?	10
What would you improve about your gorilla research procedure?	10

Of these criteria, the last question asked students to suggest improvements to the research design. I believe this specific question was an important step for developing the thought pattern of reviewing and evaluating the design of research, immediately following the students’ experience. The use of this focusing question in the rubric guided students to think critically about their experience so they could generate new ideas for designing a research study. Therefore, I believe the teacher has scaffolded one of the most meaningful and productive aspects of science as an inquiry process by making review and revision of the methodology an explicit learning goal. Processing scientific data by making inferences and designing an investigation based on the results of a prior investigation complete the cycle of inquiry and improve students' abilities to function as problem-solvers. Reflection on research design was an essential component of the inquiry process. Students reflected and wrote about the design of their zoo study and suggested improvements that are interpreted in Table 3.2.

Table 3.2 Students' cognition regarding the concept of research design

Random excerpts from students' research proposals	**Description of students' reasoning about designing investigations**
"Things I would like to improve are the time and points of view. My partners and I wish to have more time and more angles to observe gorillas. And also I would like to have a air-condition room around the gorillas so I wouldn't get uncomfortable during observing."	Length of time and position of observer in relation to subject are important for data collection
"Make our data more valid by observing the adult female gorilla all day for several days."	Length of time related to increased validity
"To improve my procedure, I would watch the gorilla for hours and days at a time."	Length of time related to increased validity
"We could have stayed at the zoo the whole day and got some valid info."	Length of time related to increased validity
"I think using an ethogram was a good way to collect data, but the ethogram needed to be more detailed and have more categories. For example, the social and solitary behavior categories should have had sub-categories that went into more detail of what kind of social or solitary behavior the gorillas was doing. Also, I think there should be an out-of view category because sometimes you can't see what the gorillas is [sic] doing."	Refining and integrating new information into experimental design (ethogram)
"What I would improve about my experiment was my watch on the gorillas and my ability to see what she was doing. If I could get closer or blend in with the gorillas then I could see what they were to	Relating knowledge of animal behavior to accurate data collection

do without them feeling threatened or watched."	

The students' suggested improvements provided insight into their understanding of the nature of science as being subject to revision. Scientists constantly reevaluate and revise research designs based on their experiences and results; here students are learning how that process takes place. They acted as scientists to evaluate the effectiveness of their research design.

With that experience, students proceeded to the "What can we learn from bones?" and "What can we learn from skulls?" lessons, introduced by a discussion of extant mammals vs. extinct animals. The guest teacher used review questions to support and scaffold the students' data collection and reflective notes. The guidance provided by focus questions was meant to steer students in a content-related direction, but refrained from commanding explicit outcomes:

- What are the functions of bones?
- What are the functions of the skull?
- What do animals eat?
- How do animals eat?

These questions have multiple answers that may generate different ideas and thoughts about animal structure and function, which is a good characteristic of a rich inquiry environment that promotes the discussion and exchange of students' ideas and comparison of data. Students were asked by the guest teacher, "How are female lowland gorilla skulls similar to male skulls?" and one student responded that "They both have canine teeth." The discussion moved along to the differences between the skulls, and a student responded "size, the female teeth are much smaller." Another student added, "males have a larger sagittal crest." Students made a number of comparisons based on differences in size, indicating their increasing familiarity with size as a significant concept for accurate description and representation in biology.

When the teachers brought the Gorilla Motion Modeler software into the classroom, they had to provide students with a framework for using the technology and a performance-based task. A short outline listing basic steps on the blackboard helped students to get started:

1. insert new key frame
2. use software to make small movement
3. move gorilla on the axis using arrows
4. save (update current key frame)
5. insert new key frame

With just those simple instructions, the classroom teacher began guiding students through the process of making an animated clip of gorilla movement. The scaffolding provided by the teacher established an environment for discovery learning and collaboration.

CT “Tell me what it does when you click ‘roll.’”
S “It rolls in a clockwise direction.”
CT “What does it do when you click ‘pitch?’”
S “It moves in a circle.”

Notice how the teacher asked students to perform an input action and report their results back to the classroom. Students were given a task that required them to create a product, animated clips of gorilla movement. The clips were used to generate an end product of technology, a video clip of sequential animation frames: “Create your animation.” The task required students to apply their knowledge about gorilla behavior and motion. The teacher framed the task more specifically: “Your goal is to create movement, and in order to make the gorilla move, you have to move its body.” Once again, the teacher has framed a problem or goal for the students and provided initial stepping stones in the form of outlines, instructions, or questions for students’ to work from in developing their own product.

Following the use of the Motion Modeler and the investigation into bones, skulls, and fossil evidence of hominid bipedalism, students presented their independent research projects.

Thirty-six presentations were evaluated for evidence of student-driven inquiry into the topics of research on animals and hominid origins. The students were encouraged by the curriculum and the teachers to research their own areas of interest and were provided with some suggestions and ideas. The suggested species for investigation included humans, gorillas, dogs, cats, wild cats, and the horse. The activity also reviewed the extinct species that were used as fossil evidence in the classroom: *H. neanderthalensis*, *A. afarensis*, *H. ergaster/erectus*, and *H. floriensis.* Topics related to locomotion included the energy efficiency of bipedalism, the freedom of hands for food gathering, the ability to see over grass and avoid predators, the ability to provision for offspring and carry babies, the freedom of hands for tool-making and weapons, and the ability to travel long distances and track migrating herds (Lewin, 2003). The suggested format for the presentation is provided in Table 3.3.

Table 3.3 *PowerPoint* presentation rubric

Slide	**Topics**	**Points**
1	Title Page with Names of Researchers	3
2	Your Research Question	3
3-7	Data (pictures/statements/evidence) that Supports and Answers your Research Question	12
8	Concluding Summary	3
9	Bibliography	6

The research supports the practice of providing students the criteria upon which they will be evaluated: "The manner in which students receive feedback is important for student achievement. . . In nontechnical terms, this means providing students with feedback in terms of specific levels of knowledge and skill is better than simply providing students with a percentage score. One powerful set of tools to this end is rubrics" (Marzano, 2001, p. 99). Additional rubrics included in the curriculum were for the research proposal and the *PowerPoint* presentation (see Table 4.1). Formative assessments included a rubric for students' drawings and labels of skulls and teeth (Table 3.4).

Table 3.4 Point values assigned to criteria from the "Drawings and labels of skulls and teeth rubric"

Feature	**Point Value**
Magnification	1
Drawing teeth (incisor, canine, premolar, molar)	8
Labeling teeth	4
Dental Formula	4

Teacher models scientific inquiry

Students' focus was guided by the teacher's use of focus questions that were described and observed in the classroom observations. These focus questions essentially modeled the thought processes required for constructing appropriate actions for research, such as, "As a scientist, what can we infer from this data?" Following the scaffolded activities of data collection gorillas and fossils, progression towards a student-driven data collection and complete research investigation was appropriate. Most importantly, students had the experience of using evidence to answer a research question, generated in the classroom with teacher guidance. They developed their own question based upon their interests, and initiated the process of a more complex, inquiry-driven, focused research investigation. The focus questions demonstrated how a scientist would seek to relate the structures of an organism with survival function and behavior, a fundamental theme found in many biological investigations. The guest teacher reinforced the concept of form and function:

GT "So what are teeth used for? How are the molars different from the incisors? Look at the flatness, the surface area. . . Why do we have teeth anyway? What is the role of teeth?"

The ensuing discussion referred to food breakdown and the function of teeth, followed by another teacher-constructed comparison of a hawk's beak to a tooth and the idea of frogs and snakes lacking teeth because they don't chew.

The environment of the classroom supported a rich learning community, as a direct result of teacher commentary about the nature of science. As the students became more aware of the value of these types of questions for biology, evidence of their appropriate additional questions surfaced. One student asked:

"Why would the herbivore have canines if it doesn't eat meat?"

The guest teacher continued to specify active thought processes that were cornerstones of the students' investigatory activities with learning objectives such as: "Observing, drawing and inferring diets of extinct organisms using fossil evidence." Students continued to examine extant mammals and compare fossils in order to generate productive ideas regarding structural features directly impacting diet, lifestyle, and overall success of an organism within its environment. In order to support the nature of science as continuous problem-solving process, the guest teacher described a new piece of evidence: "There are two reasons why the author wanted to look at this skull here. . . pieces that have to be fit together as a puzzle. The original skull is kept in Nairobi, Kenya and is carefully guarded underground in a vault . . . these are a thousand dollars." The teacher is attempting to explain to students how valuable pieces of evidence may be for an ongoing investigation, because all of the evidence connects to create feasible explanations and answers.

One of the most useful actions in the classroom environment was for the teacher to continually model what he or she is expecting the students to perform independently. Both teachers modeled data analysis so that students had a better idea of what was expected of them. The teacher constructed meaningful comparisons between the skulls:

GT "If you take the gorilla and the human and put this one in-between [Australopithecus], which one is more like human?"

GT "Compare the jaw of these Australopithecus and Homo sapiens. See they are both shorter and the Homo jaw is getting smaller. Fewer teeth is the trade-off for more language activity."

GT "Think about the features, dentition, and . . . this is a skull of *H. ergaster,* found in the Turkana region of Kenya . . . and you'll see there are a lot of question marks raised in this area . . . features like the eyebrow and the teeth, more like human . . . this one actually lived with us."

The teacher continued to model to students of the importance of generating new questions:

GT "Why do we still have the sagittal crest? What was its original function?"

This question not only referred to students' prior knowledge of the sagittal crest, but related to the central "structure relates to function" theme of biology. The guest teacher proposed another comparison: "Would you say the human is more like *afarensis* or the gorilla?" As the guest teacher showed the Neandertal skull to the class, a student exclaimed, "He has a big skull!" and the teacher responded: "because we used to think brain size was responsible for changes." Another student wanted to know, "Is this skull actual size?" The comment revealed curiosity, but also the realistic response a researcher might have had regarding actual representation of models compared to originals.

Students construct descriptions based on observation

During "Gorillas: what we remember," students shared what they remembered about making observations with the class:

S1 "make observations at the end of sample time"

S2 "timeframe is every 5 seconds"

S3 "set a sampling time"

S4 "short sampling time"

S5 "use an ethogram"

S6 "objectivity"

S7 "don't make inferences"

Students' written responses obtained from their field notebooks revealed a relatively in-depth understanding of using ethograms to make observations. One student wrote, "Be specific, use shorthand, watch all the time/pay attention, have a sampling time with an ethogram, keep observed thing in sight."

The teacher established a supporting framework for students' descriptions and observations for the investigation into gorilla behavior at Zoo Atlanta. She provided a data collection sheet in the form of a grid, and let students choose the other aspects of the research design:

CT “You choose the gorilla you want to watch . . . How long do we collect data for, at the zoo? . . .You also have to choose your sampling time – choose a reasonable time, not 5 seconds, not 1 hour.”

The notion that students were cognizant of their upcoming investigation was revealed by the questions students asked during the class period before the Zoo Safari:

S1 “Will we be using the same data collection sheet?”

S2 “How many gorillas will we be watching?”

S3 “How long will we have to observe the gorillas?”

Students experienced a learning community situation when they were faced with a shared task, and here they were asked to work with a partner to collect accurate data in a 20-minute observation session at the zoo with a single primate. One student made the comment to his partner:

S1 “Make sure you understand stationary behavior.”

This student recognized the importance of coding behavior accurately. There was evidence of conceptual knowledge of the ethogram (Table 3.4) and coding of gorilla behavior that appeared in student-student interactions during the Zoo Safari.

Table 3.5 Gorilla behavior ethogram

Behavior Code	Description
Stationary	Standing, lying, sitting still, could be awake or asleep, and not engaging in any other behavior
Locomotion	Movement of animal from one place to another, walking or running (bi-, tri-, or quadru- pedal)
Social	Includes social grooming, social play, social exam, noncontact aggression, and displacement
Solitary	Includes self-manipulation (self-grooming or object exam) and solitary behavior
Feeding/foraging	Processing and consuming food, gathering and collecting food
Other	

Some examples of focusing questions used to guide the descriptions and observations made during the zoo field trip are illustrated in Figure 3.1.

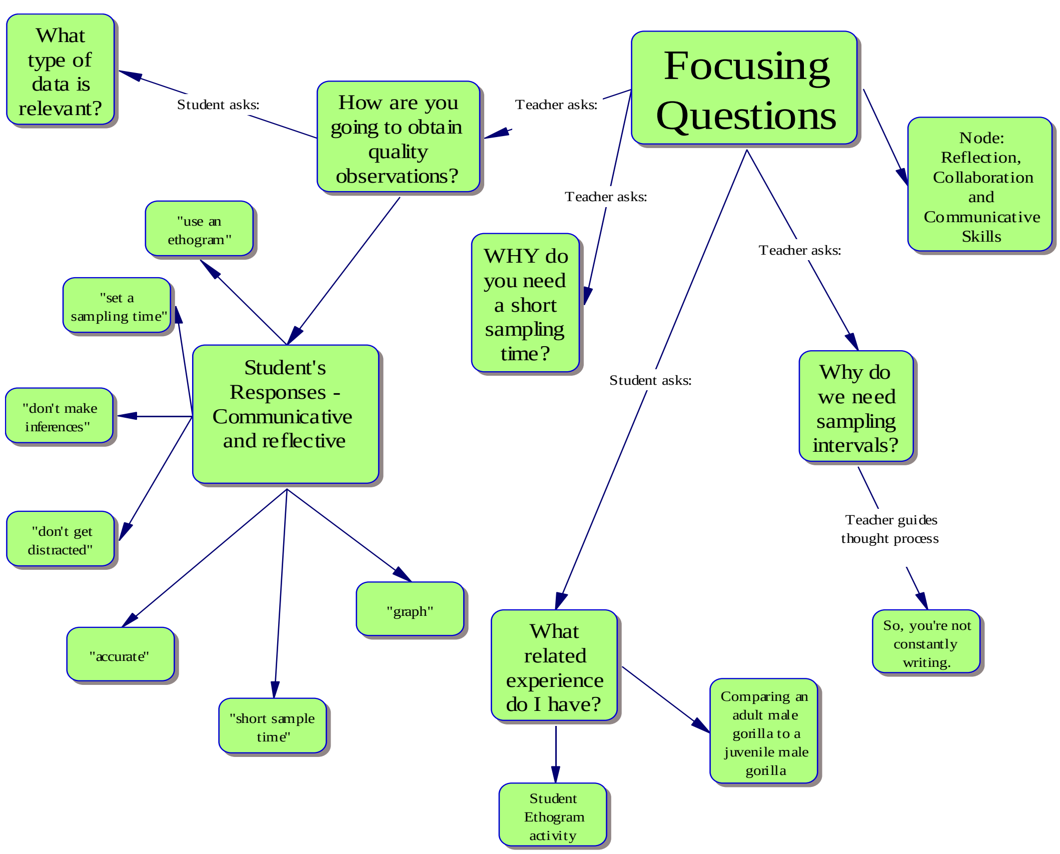

Figure 3.1 Focusing questions of teacher student interactions

Students' data comparisons lead to inferences

During the Zoo Safari, students had to compare their data with their partner at regular intervals. One student asked a question and worked toward a final decision:

S1 "Do we have social? I think we have social, that's completely social right there."

Students worked through these conflicts of data collection, and often generated important strategies for communicating. The next interchange suggested a lack of reasoning explanation between partners:

S3 "just put social"

S4 "no, cause it's not"

S3 "stationary, just put stationary"

Did these students realize the need for logical argumentation and the need for supporting explanations with evidence? The student (S3) did not make a clear compelling argument for either code. The environment facilitated student discourse, as one partner made a decision regarding the behavior and often defended that decision with supportive reasoning to his or her partner. This conflict between whether a gorilla exhibited stationary (standing, sitting, or lying down), or social (touching, looking, etc.) behavior was resolved when one student decided the code for the behavior.

The next example occurred when students watched a gorilla and made comments about the choice of sampling time. Students' interactions revealed some degree of self-evaluation already taking place, in terms of how valid students' perceive their data and the accuracy of the

the data collection process. Recall that the students chose their own sampling time, and were provided with a data collection sheet.

S1 “We should have done a 20-second sampling time, but it wouldn’t be valid data”

S2 “Are you doing every 30 seconds?”

S3 “That’s what we did.”

S2 “It’s a good thing we are doing 30 seconds, because if we did 10 seconds. . .”

The students’ learning environment provided more evidence of activities promoting the comparison of data through teacher scaffolding of students’ learning objectives. What made these data comparison activities so effective was the fact that students generated their own data, formatted and arranged the data display independently with technology support, and then made their own comparisons among the different data sets. Students were asked to compare the graphs of gorilla behavior from the class, as they are all taped to the front board.

Later, students further developed their ability to make meaningful data comparisons during the bones and skulls investigation. The students’ learning objectives included:

- compare and contrast the anatomy of skulls
- compare and contrast dentition (teeth) and use the dental formula
- develop knowledge of relationships between form and function

The scaffolding of data comparisons by the teacher appeared to significantly enhance the culture of inquiry in the classroom. Examine the following interaction between the teacher and students for a comparison of a frog skeleton and a bird skeleton. These were simply held up in front of the students and the teacher asked: “What similarities do you see in the frog and the bird?”

S1 “They have bones”

S2 “They have toes on each foot”

GT “So those are similarities. Is there a difference in the number of toes?”

S3 “The frog’s feet are facing out but the bird has feet pointed forward”

GT “What does the bird do to move? What does the frog do?”

The last question was another example of the teacher redirecting the question back to the student, to reinforce the inherent theme with the objective of learning about structural and function relationships. Students developed more awareness of appropriate comparisons for their investigation, a three-way comparison between a gorilla skull, a human skull, and a dog skull was presented. Students were asked to observe the fact that the eyes look forward on the gorilla and human skulls, and the two skulls were used as an example of a meaningful comparison that differentiated details between organisms that could be observed as valuable data.

There was evidence to suggest that students incorporated previous data collection activities into their mental models for how to construct comparisons among fossils. One student noticed the foramen magnum ridge on the skull and compared it to his knowledge of the human skull. “Look this skull has a ridge just like we are.” Whereas another group of students noticed what appeared unusual and worthy of a question: “How come there is a little hole here?” Another student responded with an idea about possible functions for the structure and generated a productive interchange: “Maybe it’s for muscle attachment.”

Students appeared to generate more questions and discussion, although it was difficult to interpret whether the cause was related to new material in the form of large skull replicas, or increased familiarity with the methods for collecting and analyzing data. The increase in discussion provided greater insight for the teacher to quickly assess concepts and ideas that are part of student discussion. More student interchanges that presented evidence of students' constructing initial data comparisons independently include:

S1 "Are these teeth right here? Our teeth don't feel like that."

S2 "*afarensis* is more like human"

S3 "If you look at the back of the skull, it looks bigger than a human."

S4 "There is a story about Neandertals being cannibals and they contracted Kuru and went extinct."

S5 "Yeah his jaw is really far out."

GT "Do you see anything else?"

S1 "It has the same amount of teeth and the eyes look similar."

S2 "It also got a lot of surface area on the side."

The student furthered the analysis and identified another feature, the sagittal crest, for comparisons among species. Students learned of the sagittal crest during the gorilla unit in the spring and integrated the feature into the human origins investigation:

S2 "That looks a lot closer to us, that's got the sagittal crest and everything."

Additional questions were generated about the brain and the relationship of human brain size to behavior. Students appeared interested in human brain function and would relate the functioning of the human brain to many of the hominid species depicted with fossil skulls. A more complex version of the question, “Could hominids of the past have brains different from a human?” provided a direct link to the breakthroughs in modern research on hominid evolution: S1 “Can’t a human have a different kind of brain, like a manatee has a very smooth brain, with less folds?”

Some students made inferences from their data as it was collected. One student inferred that a hungry gorilla would move more slowly because it is weaker:

S1 “Why is it so slow?”

S2 “Because it’s almost feeding time.”

S3 “Why are we specifically studying gorillas? Are they the most like humans?”

Conceptual knowledge of data analysis was supported by carefully constructed comparisons where one variable was changed. Students have been involved in activities throughout the year focused on improving their ability to make comparisons among different data sets to facilitate inferences and drawing conclusions from the data. (see Figure 1.3).

I developed a simple comparison of two gorilla data sets to evaluate students’ level of conceptual understanding for authentic data comparisons. The goal of the “Dr. Zhivago study” was to evaluate the reasoning students used to justify their choice of a particular data set when faced with a scenario involving comparison and inference of collected data. I sought to characterize their scientific reasoning for determining the validity of data and implications for research design, in the context of the overall research investigation into gorilla behavior. Choosing one sample study time that was the same as what students used at the zoo for the comparison was intentional in order that the students could relate more directly to their Zoo Safari experience. Did students have a conceptual understanding of representative sampling intervals following their experience with a primate ethogram and direct observations at Zoo Atlanta? What were their ideas and initial conceptual constructs regarding accurate data collection? The Dr. Zhivago study was a simple assessment in which students wrote their position on an “admit slip” after being presented with the following scenario (Table 3.5).

Table 3.6 Dr. Zhivago’s study

Dr. Zhivago compared the data graphs of these two gorillas, both with the same habitat, and he concluded that he would use gorilla B for his study of gorillas that exhibit high levels of social behavior. ***Gorilla A*** sample time = 20 minutes sampling interval = 10 seconds ***Gorilla B*** sample time = 24 hours sampling interval = 12 minutes Would you support his conclusion to use gorilla B for his new study? Why or why not?

The responses of students were entered into a standard pie chart in Figure 3.2.

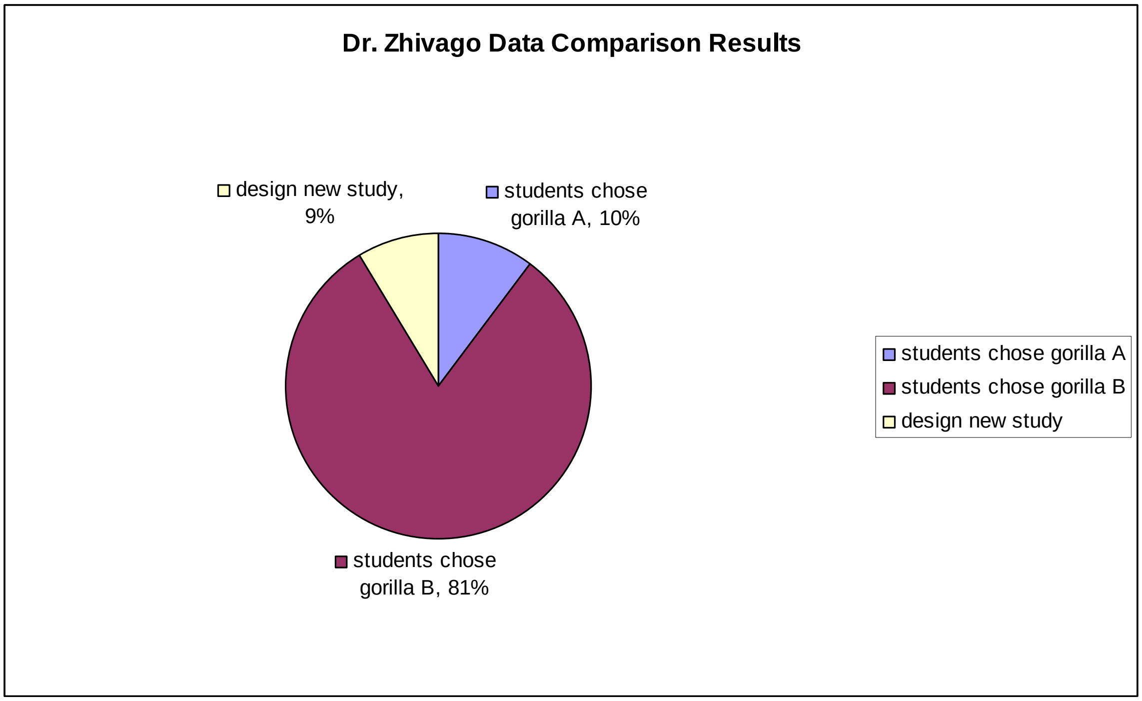

Figure 3.2 Dr. Zhivago data comparison results

The students determined that these two data sets had significant deviation in experimental design, indicated by a majority of students (81%) who preferred to utilize the data from the study with a longer study time, 24 hours, over the study with a shorter study time of 20 minutes. The students' choice was influenced by their prior research experience at the zoo, where students experienced firsthand whether a study time of 20 minutes is representative of gorilla behavior. Many students wrote and commented in their field notebooks that 20 minutes did not represent the activities of a gorilla throughout the day. The students provided reasoning to support their decision of using either data set, describing the study time as valid or not valid and often justified with descriptions such as: "a gorilla can do a lot in 12 minutes." This student is expressing the idea that gorilla behavior occurs constantly, and the researcher will "miss" certain behaviors with a long sampling time. Apparently, the concept of longer study time compensating for longer sampling time was not established.

An interesting occurrence in student thought patterns was revealed in six student responses, where the student firmly suggested a redesign of the study to compare data sets with just one variable. These students concluded that controlled data comparisons with one variable change were necessary to draw reliable inferences, so they justified their reasons for choosing a new design when asked to make a decision between the two data sets.

The guest teacher promoted critical inquiry thought processes when he asked students, “Why do you think it is important to have a smaller set of teeth?” The question required students to make an inference and students hesitated to answer. The teacher did not provide the answer, though, and instead conducted another skull comparison, between the mountain lion and the human. The technique left some unanswered questions still “hanging in the air.”

The next set of guiding questions focused students’ inquiry on the current hypotheses for origins of bipedal locomotion. Each set of guiding questions focused on a significant concept of human origins. For example, the three-dimensional field of vision, whereas other animal, i.e. the dog, have eyes on the side of the skull. Several more students generated questions about skulls affecting speech:

S1“Isn’t the jaw at the top of the skull also to help vocalization?”

S2 “How come the gorilla has pushed in on the sides (motioning with hands on sides of head) but the human is more round?”

S3 “How do you have the ability to speak?”

GT “You need a tongue and teeth and vocal chords”

S “Parrots can speak.”

The teacher answered the student’s question by identifying components of the speech process, and the student quickly came up with a contradictory example, from their point of view. The environment indicates a dynamic scientific community with support and encouragement for differences or contradicting arguments.

To facilitate comparisons amongst different sources of data, students had different skeleton models of animals in groups. Students recorded their data in their field notebooks. Later the teacher asked students about their work:

GT “What did you learn about the frog?”

S1 “The legs look like they are adapted for hopping. same number of bones”

GT “How are they different?”

S1 “back ones are longer for”

S2 “jumping, hopping”

GT “What is the name of this crest on the top of the skull?

S3 “sagittal”

The introduction of skulls, bones, and skeletons as evidence for the physiology and behavior of animals allowed students to experience how scientists compare features of organisms and draw conclusions based on what they observe and the inferences they are able to make. These lessons provided strong evidence for the effectiveness of guided comparisons in teaching students how to construct appropriate data analysis.

GT “This is a caveman from Europe. When you compare their dentition to ours, what do you see?”

S1 “Big head”

S2 “They are very big and have very big teeth.

GT “The gorilla had big canines, so they probably had very different social organization than the gorilla. Gorillas had a much coarser diet.”

S1 “When did Neandertals go extinct?”

S2 “What’s this ridge around here?”

GT “That’s for muscle attachment.”

S3 “So that’s like an omnivore, I guess.”

S2 “So H. ergaster came before A. afarensis?”

Students brought their own questions into the environment based on relationships between their background knowledge and new concepts that were introduced based on the evidence from fossils Students were able to come up with verbal descriptions of their observations, and some students set up a comparison between skulls of the gorilla with *H. ergaster*. More evidence for students developing their own questions continued to surface. Students had practice with research questions and designing experiments following their gorilla investigation. Students generated their own questions during classroom discussions that revolved around the evidence.

Students’ data analysis drives reflection

During the field trip to Zoo Atlanta, data was obtained about the interactions that occurred between student pairs as they conducted their data collection. These interactions stimulated reflective thought patterns students demonstrated in both the classroom and during the observation session at the zoo. The map of reflective collaboration and communication was designed to support the patterns of student thinking by integrating authentic verbalizations from the classroom with the guiding questions asked by the teacher to provide a description of scaffolded inquiry.

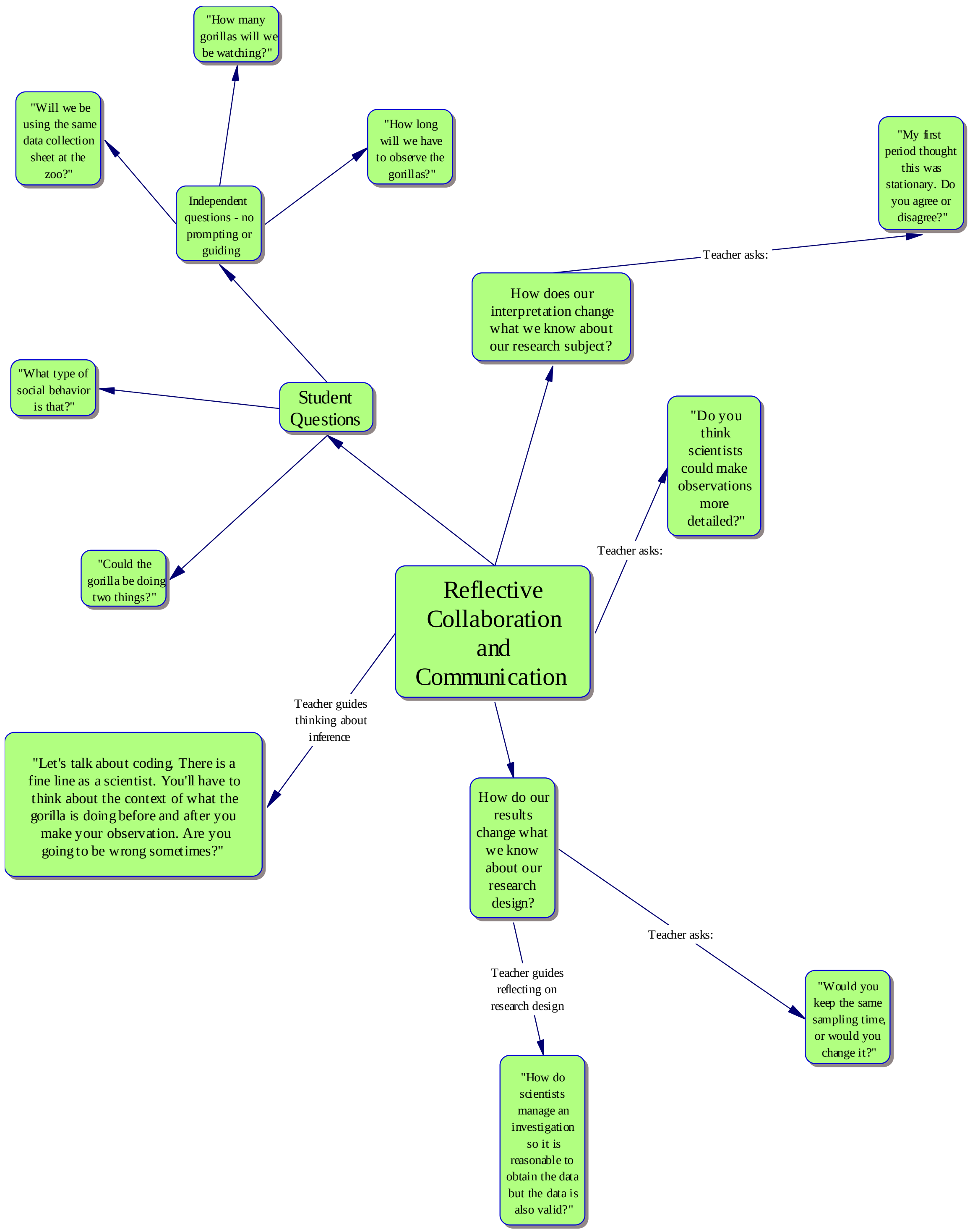

Figure 3.3 Reflective collaboration and communication

Some students began to provide reasoning for their choice of coded behaviors, or to explain their choice for one over another:

S3 “Social behavior”

S4 “Wait, no it’s not”

S3 “right, it’s locomotion”

S4 “You can’t tell sometimes, you have to choose the most obvious”

Shared experience formed a basis for reflecting and analyzing the scientific processes that occurred during the investigation. In the previous example, interaction established meaningful thought processing for the learner. She could have either accepted the student’s explanation as true, or asked for more supporting evidence, or rejected the reason as unsupported.

Evidence from student’s research proposals provided students’ the opportunity to reflect on their reasoning for choosing a certain sampling time at the zoo, the validity of their collected data, and the improvements to research design. The writing activity enhanced clarification of specific ideas and concepts students held and allowed the teacher to evaluate student learning and obtain student feedback for formative curriculum development.

Direct quotes from student’s research proposals were interpreted to evaluate students’ level of reasoning about the topics of sampling time.

Table 3.7 Students' responses and corresponding interpretations of reasoning

Random excerpts from students' research proposals	**Description of students' reasoning for choice of sampling time**
"My partners and I chose 15 seconds as our sampling time. 15 seconds is reasonable because 20 seconds is too long and 10 second is too short."	Comparing to extremes
"I made observations every thirty seconds (because we had forty blocks on our data collection sheet) for twenty minutes"	Scaffold provided determination of sample time
"I chose this sampling time because I picked a time between a sample that was too short and a sample that was too long. I also based my choice on what would be reasonable for me and what would be reasonable for getting valid data about the gorillas."	Compare to extremes, concept of "reasonable" applied to experiment
"Our sampling time was 20 seconds and we chose that time because it was convenient."	Sample time was based on scaffold, not verbalized reasoning
"I used thirty seconds as my sampling time because it wasn't too long or short of a period of time. . . Using thirty seconds as a sampling time was a good amount given that we only sampled for twenty minutes."	Comparison to extremes on either end
"I choose this time frame because I didn't want to go so quickly that I might miss some of what she was doing and I knew that she might be active so I didn't want a lot of the same behavior in many occurrences."	Concept of representative ness: seeking a reasonable representation of gorilla activity

Validity was central to acceptance of data as representing the subject under study. Students' reasoning about the validity of the data they collected was also evaluated to provide evidence of students' inference abilities.

Table 3.8 Students' cognitive development regarding the concept of validity

Random excerpts from students' research proposals	**Description of students' reasoning for inferring validity of data**
"This behavior was not representative of what she does all day."	Limited time for study
"My data is probably not valid for a representation of the activity of an adult female gorilla because I only observed her for twenty minutes and she was also in captivity which could mean that her behavior could be different from an adult female gorilla in the wild. The weather could also have impacted my results."	Captive gorilla may not represent wild gorilla Weather (environmental influence) affects animals Small sampling not valid for drawing conclusions
"The information we got is not valid (to me) because if we were going to find out what the gorilla does in its day then we would stay at the zoo the whole day"	Length of sample time not valid
"I don't think that my research is valid because if you only observe for twenty minutes, you can't conclude how a gorilla spends its day."	Length of sample time not valid
"I only sampled for 20 minutes, and that can't be representative of what a gorilla does the whole day, and maybe the gorilla I studied was abnormal and didn't act like the other ones so I would have to do much more research on different gorillas for a much longer period."	Length of sample time not valid

Reflective writing was a significant component of inquiry-based classroom activities, as students were asked to write continually about questions, such as "What are the functions of bones?" into their field notebooks. The concept of bone function was introduced as a focal idea, to assist students with constructing meaningful comparisons. Do structures of bones have the structure and form that they do? The students were prompted to share their ideas with the class, and the functions of bones and skulls are organized on the board for all students to record in their field notebooks. Students described and wrote about their own chewing, a simple direct and personal comparison that requires students to focus conscientiously on chewing a cracker. Once students have shifted their focus to their chewing, the discussion about dentition and diet had a more meaningful context.

The comparison of skulls was facilitated by the use of a mathematical tool, the dental formula, which provided a description of the number of incisors, canines, premolars, and molars. With this tool, the students quantitatively described the differences in the teeth of different animals and analyzed their comparisons as authentic data. Initially, they were introduced to the idea of using the dental formula to compare among their peers by the guest teacher:

GT "How many of us had 32? . . . Okay, I've given you some dental formulas for other animals. The sheep, the pig, the dog."

The teacher further developed the idea for students that comparisons among different animals were enhanced by using the dental formula as a comparative tool. Previously, students had no basis upon which to evaluate differences in teeth, jaws, or skull shape except in descriptive terms. There was no quantifiable, statistical numeration to describe dentition. With the dental formula, students now possessed a tool for constructing their own comparisons based upon what questions they were interested in answering. The guest teacher furthered this idea and introduced another animal: "Like the alligator, does the alligator chew its food? No it does not. So those carnassials are very special teeth for carnivores."

Students' rich experiences form the basis for communication and questioning

The interactions between students indicated a learning environment that supported and encouraged students to delve into productive discussions that required students to verbalize and create descriptions of the mental thought processes. The increased use of language served two purposes in the inquiry-based learning environment. First, 1) students confronted their ability to communicate their knowledge construction of a particular term, issue, topic, or concept, such as coding, sampling time, ethogram, stationary, behavior, etc. and 2) students re-evaluated and confirmed their knowledge in reference to others' communicated ideas. This helped to reinforce the validity of description and observation, and build confidence in students' ability to construct questions. The richness of the learning environment promoted reflective open discussion about the techniques that were being used, and maintained their reliability as a method.

The environment was further enhanced when students presented their *Power points* as performance products. Students' main ideas were described on either the 1st or 2nd slide, and main topics were often the project title. "Main idea descriptions" were categorized as 1) description, 2) compare/contrast, 3) questions beginning with the word "Why or How" (described as 2nd level inquiry), and 4) those beginning with the word "What or Who" (described as 1st level inquiry.) Some "main ideas" include both an inquiry element and a descriptive or comparative element. Some students demonstrated the critical analysis required to draw inferences and conclusions from data. The right hand column contains the identified research question, if included, and topics or concepts covered in the presentation that support the main idea. Some presentations included a research topic, but did not contain a research question. Those presentations have a blank square under the 'Research Question.' The analysis from the *PowerPoint* presentations is summarized in Table 4.1.

Table 4.1 *PowerPoint* research presentations

Project Title	**Main Idea Designation**	**Research Question (in "quotes") / topics**
Being Bipedal	Description/observation	Energy efficiency, use of hands, camouflage and predation Applications: fly airplanes, drive cars, running, driving, building
Evolution vs. Creation	Comparison/Contrast	Carbon Dating
Oldest Fossil Ever	Description/observation	
Giraffes vs. Lions	Comparison/Contrast	Giraffe skull – herbivores
Herbivores vs. Carnivores	Comparison/Contrast Description/observation Inquiry – 1st level	"What's the difference between Gorilla gorilla and Puma concolor dentition and skulls?" diet, dental formula, skulls
Gorilla Food Web	Description/observation Inquiry – 1st level	Food adaptations: large molars, large canines, opposable thumbs, variety of food
Neanderthal Man	Description/observation Inquiry – 1st level	"Who are the Neanderthal men?"
Otter vs. Lynx	Description/observation Comparison/Contrast Inquiry – 2nd level	"How does an otter compare and contrast to a lynx?" facial features, diagrams of body plans
Similarities and Differences between Gorilla and Homo sapiens	Comparison/Contrast	Differences: classification, herbivores, quadrapedal, large canines Similarities: opposable thumbs, no tails, mammals, reproduce sexually, same dental formula, males bigger
Family Hominidae	Description/observation	
Running	Description/observation Inquiry – 2nd level	"Could natural selection favor humans who ran long distances?"
Coyotes	Comparison/Contrast	Comparison of wolf and coyote skulls Comparison of coyotes and bush dogs
Homo floriensis	Description/observation Inquiry – 1st level	"What are H. floriensis?"
Bipedal vs. Quadrapedal locomotion	Comparison/Contrast	
What can we learn from skulls?	Description/observation Inquiry – 2nd level	
Australopithecus afarensis	Description/observation Comparison/contrast Inquiry – 1st level	"What are the similarities and differences between A. afarensis and H. sapiens?" differences: skeletal systems, dentition and diet, classification, brain, similarities: bipedalism and dentition
Is evolution the result of our existence?	Description	

Gorilla classification	Categorization	History and taxonomy of gorillas
Comparing the Neanderthal man and the flores man	Comparison/Contrast	Classification Location of discovery Time periods
Eating habits of the lynx and the opossum	Description/observation Comparison/Contrast Inquiry – 2^{nd} level	"How do feeding habits of the lynx compare to the opossum?" lynx diet vs. opossum diet comparing carnivores to omnivores: molars-canines skulls comparison
Hippo skulls and teeth	Description/observation Inquiry – 2^{nd} level	"Why do hippos have big canines if they are herbivores?" description teeth and feeding Hypothesis is that hippos have large canines to threaten others and defend themselves
How and what do Canis latrans eat?	Description/observation Inquiry – 2^{nd} level	"How do they gather food and what do they eat?" I 1/3, C 1/1, PM 4/4, M 2/3 skull description hunting appearance
Locomotion in Mammals	Description/observation	Descriptions of "dog walk", "giraffe walk", "trot," "gallop" "leaping" 20% of species flying bipedal locomotion – H. sapiens
Lynx Canadensis	Description/observation Inquiry – 2^{nd} level	"How efficient is Lynx locomotion (quadrapedal) compared to bipedal locomotion (two legs)? Description adaptations Prey Comparison to bipedal locomotion locomotion Conclusion : Since lynx's prey considered mostly snow hare, this is an important adaptation, thus more efficient. Questions: Why is tip of lynxs ear black? Why are the paws bigger?

Penguins	Description/observation Inquiry – 2nd level	"Why do penguins have wings and can't fly?" b/c of heavy bones Feathers are heavy, waterproof, Penguins paddle water instead How and what do penguins eat? Are penguins bipedal? How can penguins see underwater? large eyes, flat corneas, bilateral vision
Skeletons	Description/observation Comparison/Contrast Inquiry – 2nd level	"How are human and chimp skeletons alike?" Compare # of bones in humans skulls (22) vs. chimp skulls (18) Similarities of skulls Similarities of backbone Comparison of vertebral column Comparison of hands Did you know? Conclusion: Humans and chimps are alike in many ways, but the skulls are different as well as the vertebral column.
Skulls	Description/observation Comparison/contrast Inquiry – 2nd level	"Why aren't gorillas bipedal all of the time?" Comparing skeletons Comparing pictures of skeletons Locomotion: gorillas support weight on the outside of the hand and climb in trees Conclusion: gorillas are bipedal because of the structure of skeleton that our bodies are held up by. Gorillas aren't bipedal because they have a different skeleton buildup, for gathering food on the ground. That is why gorillas aren't bipedal all of the time.
Forensic Anthropology	Description/observation Inquiry – 1st level	Application of anthropological knowledge and techniques in a legal context "What can you learn from bones?" age, gender, height, weight, racial group and occupation

Humans vs. Dolphins	Description/observation Comparison/Contrast Inquiry – 1st level	"What are the main similarities and differences between the skeletal systems (and other body systems) of H. sapiens and Tursiops truncates (bottlenose dolphin)? Skeleton pictures diagrams Similarities: common bones = ribs, vertebral column, phlanges, pelvis Differences: bones = leg, knee, patella, metatarsals, wrist and elbow Random facts about the brain Conclusion: there are many similarities and differences
Comparing and contrasting the dentition of carnivores and herbivores	Description/observation Comparison/Contrast	Sheep vs. dog skulls Herbivores description Teeth of herbivores Carnivore description Process of chewing – candyloid process major jaw muscle – temporalis Summing it up: same teeth but also different, carnivores eat meat and herbivores eat animals Jaws designed for grinding up plants and carnivores jaws are designed for killing and grasping prey
Monotremes	Description/observation Inquiry – 1st level	"What did the monotremes evolve from ?" "What are 3 different species of monotremes and some of their characteristics?" description of monotremes duck-billed platypus classification: fossil vs. modern short-beaked echidna classification evolution – unknown Conclusion – do not know other conclusion – 3 species of monotremes are 2 species of echidna and 1 platypus
Tiger locomotion	Description/observation	Being quadrapedal has advantages and disadvantages for tigers, benefits outweigh problems

Differences between H. neanderthalis and H. ergaster	Description/observation Comparison/Contrast Inquiry – 1st level	"Looking at the skeleton, what are the differences between the 2 species?" H. ergaster discovery H. neanderthalis discovery What we noticed in the skull: upper lip, cranium, same teeth, more human look = neander more ape look = ergaster What we noticed in the skeleton: H. ergaster taller, smaller pelvis, more rounded ribcage H. neander wider, more ribs Conclusion We cannot draw one conclusion because there is no one difference, but many small, like the skull, height and time they lived.
Penguins	Description/observation Inquiry – 2nd level	"How do emperor penguins survive?" general information about penguins
Basilik (Jesus) Lizard	Description/observation Inquiry – 2nd level	"How does basilisk lizard run on water?" Does its skeletal system help it? Do the webbed feet help? How far and how fast can they run? General information classification running on water How they use the ability
Saber Tooth Tiger's Canine Teeth	Description/observation Inquiry – 2nd level	"Why did the saber tooth tiger have such big canine teeth?" used teeth to pierce flesh easier than other animals slow moving, so hunted slow moving animals many useful fossils to finding true purpose of canine teeth

After evaluating the students' research findings, evidence was obtained to support the framework for inquiry-based learning that begins with making descriptive observations and constructing meaningful data comparisons that lead to valid conclusions. Most of the students attempted to provide their audience with both verbal and visual depiction of the animal or hominid they chose to study, and many included descriptive explanations of diet, dentition, herbivore or carnivore, classification, opposable thumbs and structural features of skeletons. In many presentations, there was a logical sequence of investigation as shown in the "main idea description" column: description/observation → comparison/contrast → answer to inquiry-based research question. The fact that students followed this pattern independently based on their previous inquiry experience and the rubric provided indicated an increasing aptitude for designing and conducting research.

Technology promotes interactivity

The teacher guided the use of Microsoft Excel for graphing data. Students' data was obtained from their observations during the Zoo Safari and categorized within a real ethogram (Table 3.4) developed by primatologists. An ethogram is a carefully coded categorization scheme, often used for the study of animal behavior. In the computer lab, students sat in clusters of two, three or four among the diagonal workbenches and interacted during the graphing activity. The teacher directed students to perform several actions that connected the information provided by the graph to the focus of the investigation. She reminded students about the experimental question, sampling time, study time, interpreting the graph, and future questions for research. The computer lab environment seemed to facilitate interaction between students, as seen in the following interchanges:

S1 "You might want to talk more about your experimental question."

S2 "What is an experimental question?"

S3 "My data for the graph would not be valid"

S4 "Construct a pie graph to go with the bar graph."

S5 "Whoa, what was your sampling time?"

S6 “10 seconds”

S5 “Ours was 20 seconds”

Another important feature of technology used during inquiry-based learning was the use of emergent technology with the Motion Modeler. The application of technological tools was a significant technique for simulating real scientific research. The NSES lists the “use of tools to gather, analyze, and interpret data” as one of the inquiry standards. Appropriate utilization of technologies in the classroom was directly related to the teacher’s direction and guidance. Since recently adapted from flight simulation software developed at the Georgia Institute of Technology, there are no step-by-step instructions. Realistically portraying the limits of an emergent technology, the teacher facilitated students’ investigatory use of the software. Students were asked to construct a motion and then assemble the clips to create a movie. They worked on their projects in groups of two or three and constructed from 10 to 60 frames. Students utilized procedural knowledge and combined those tacit actions with knowledge of gorillas and their movements. The following excerpt demonstrated how students were guided with questions:

GT “Click on a particular bone and it will highlight or turn red. That means you can move the particular bone . . . Now you just create one frame at a time and save that piece, then move onto the second frame. Then what do you do?”

S1 “Make the second frame. How many frames do you need to show a gorilla walking?”

The example demonstrates how the student understands the concept of individual frames that compose the animated motion, which is an essential component of both virtual modeling, and overall thought processes of inquiry. During the modeling process, several interesting exchanges occurred between students that revealed students’ thoughts about technology as a modeling tool for data representation. Students often illustrated the common association of anthropomorphism by making the gorilla movement imitate dancing, scratching, jumping, or posing. The student in the following excerpt was enthusiastic about the possibilities of implementing his ideas for the gorilla animation clip:

S "What if we could make him fly? This would be so cool if it was touch screen. It'd be so cool if we could make it do head and shoulders knees and toes. We can do it too! Want to do it?"

Technology blends science with constructivist learning

The use of Excel software within the environment of a computer lab provided students with a tool to display and analyze the data that was collected, in a graph form that enabled thinking about relationships among ethogram categories. Additionally, student interactions occurred within the context of the graphing task, and allowed students to recognize alternative explanations and to assist with technological details. The activity guided students with a framework, but the explicit details of the graph were the responsibility of the student. Students discussed goals of their data display, as in this excerpt from field notes:

S1 "What are we doing for the y-axis?"

S2 "It says on the sheet number of occurrences. Why can't we just put frequencies?"

S1 "It doesn't say if we should do it in rows or columns."

The Motion Modeler provided an exemplary use of technology in an inquiry learning environment. Student learning with this emergent technology was directed by teacher questions, but demonstrated students' ability to construct meaning through computer-based models and technological tools. Students used a virtual reality gorilla able to move about a three-D environment based on students' input of commands *such as* "pitch, roll, and yawl." Students constructed their own clips and movies as virtual reality scientists. This activity provided an engaging use of technology for students to develop knowledge of evidence and models for scientific explanation. Learning was directly through experience, within the framework of a specific task that connected to the overall investigation into gorilla behavior. Students were initially interested in anthropomorphic movements related to human behaviors such as dancing, scratching the head, and clapping hands. Students learned to connect their commands to the gorilla's actions, and built different frames of gorilla movement. The level of interaction between members of the group increased as ideas were generated and communication was required. The students began to support their own discovery of model functioning:

S1 "and then slide the other foot back"

S2 "What happened?"

S1 "Did it make a new key frame?"

S2 "I think we have to change the time on there too."

S3 "This is messed up"

S1 "Yeah, one foot goes up"

Students were also able to relate their activity to science, as shown in the following response to the teacher's question:

CT "Why do you think modeling would be helpful to scientists?

S1 "Scientists can understand something without actually having to go out."

Students developed a deeper understanding of research and the resources required to conduct reliable experiments. The students also developed many ideas of how the model would be improved in terms of realistic representation. The teacher asked students to reflect on the work and evaluate additional questions: “What did we learn about modeling today? Are there limits to this type of model? What types of limits?”

S1 “Facial expressions”

S2 “sounds of gorillas”

S3 “controls”

S4 “It’s movements are limited, it couldn’t do the wave.”

The student (S4) described a gap between what he knew about the motion and the desired outcomes of modeling. The technology has provided students with a hand-on learning activity they may build from to enhance their conceptual understanding of science as a process continually evolving with assistance from technological tools. The Motion Modeler portrayed a model for gorilla behavior that was subject to the control of the scientist, and capable of appropriate output when the user has clearly established outcomes for the model and a thorough understanding of model functioning.

Teacher Interview

Following the Gorilla curriculum unit activities, the classroom teacher’s responses were sought to help clarify the concepts of comparing and contrasting data sets, the nature of science, students’ backgrounds affecting the learning environment, and building an inquiry learning environment. Interview questions are shown in bold, and the teacher responses follow.

I: What is known about primate behavior regarding captive gorillas and gorillas in the wild that would help you to use that kind of data in the classroom?

“I’ve read some studies done on captive gorillas and wild gorillas, but not like comparative studies. I’m sure it’s something the kids could get into, I guess the wild investigation would have to be something that could be replicable. . . I don't really know how it would be used in the classroom, it would probably take a lot of technology, and research articles. . ."

I: What themes of gorillas and primate biology provide subject matter that all of your students can relate to, including those from diverse backgrounds?

"I think I kind of am sensitive to diverse backgrounds by giving kids kind of like a choice, you know, on whatever questions they want to ask, so they can feel like they are working on their own kinds of things…"

"I think student choice is important, let them feel like it's personal…

"Also, you try to give kids a backbone of what's expected, and guidance, but also the freedom to work within it … and then always be willing to be flexible, you know, to not necessarily penalize them if they didn't do exactly what you thought."

"And then when everybody has their own research project, they feel like they have their own special contribution that nobody else has"

"If they're all having to do a research project, they're all held accountable and they all have to produce something, which is empowering"

"I think that is a really interesting question, I mean like how do you address diverse backgrounds… there is a balance…keep the bar high for everybody, no matter what the background is."

I: Cultural evolution of hominid behavior is difficult for scientists to understand. Do you think it is useful to introduce students to the ideas scientists "grapple" with, where there are no answers yet and much is still unknown?

“I just think that’s an important kind of nature of science concept. There’s no way even if you’re just studying something very simple like plants…that’s important for kids to know, you try to be as objective as possible, but there are always going to be pieces of information left out.”

“Orrorin tugenensis, you know, didn’t link up to anything when they found it, just this bone.”

“And I think its’ important for them to have the evidence there, before they start talking about it.”

I: Would you describe an example during the unit where you thought they needed more guidance or scaffolding for thinking critically about, like the dental formula, the Motion Modeler?

“I need to set up little benchmarks, like little practice opportunities so I can see where they are at…Like I don’t know if they really had an understanding of the dental formula…”

“And I think like the skulls unit was kind of an introduction to the evolution unit, just a kind of hook to get them involved…the concept of time I think they had trouble with…”

“Getting them to produce, through writing, through some sort of project or presentation, or amongst each other, so, that they have to think.” Authentic assessment is what it’s called, I guess, I don’t really know what the word is, but an assessment where they really have to show what they know.”

“For them really to understand the concept of modeling . . . the modeler, I mean how is it connected to every other piece of the unit?”

“Initially, it started off as just the technology piece . . . and then I wanted to figure out how to make it work in the classroom . . . but the technology is more interactive, with the video of gorilla behavior clips where students can stop and start the video . . . that was a really good piece."

The interview revealed the teacher's concern for the availability and integration of technology into classroom teaching methods. The teacher seems to hold a strong regard for individual interests and unique perspectives contributed by each student. Furthermore, the teacher would like to emphasize the nature of science in the classroom, including the use of evidence and explanation through performance assessments. Acknowledgement of technology benefits such as interactivity and engaging students' interest was expressed. The benefits of technology might also be similar to the benefits of teacher scaffolding practices, or "stepping stones," that provide students with practical opportunities to practice what they have learned.

DISCUSSION

Teacher scaffolding and modeling of inquiry processes

Scaffolding inquiry tasks in the learning environment

Scaffolding provided the immediate guidance, contextual link, and connection to prior concepts required by middle school science learners. Teachers framed the task and made a difficult challenge more feasible, increasing the students' odd for success. Before using the ethogram to obtain data, students have little experience with data derived from their direct observations. The use of numbers and the plotting of graphs were utilized in mathematics, but not necessarily in science. Middle grades students have nominal experience with significant inferences from previous data collections. The VG project was an initial investigation into science for most of the participants, designed to gradually build knowledge of scientific inquiry during the lesson activities. Most importantly, leading students' to think critically and formulate their own questions resulted from the teacher's guiding questions that frame the project, and provided the scaffolding that appeared essential to inquiry teaching.

Although inquiry is a fundamental process of scientific investigation, there is no "right answer" regarding its definition or its most effective implementation. Rather, inquiry is composed of multiple thinking patterns that serve the scientist as a critical thinker and problem solver and hones the "process skills" of identifying research questions and designing experimental investigations. Science itself is a "dynamic system in which new ideas and new methodologies are constantly evolving and submitted to usability and persuasiveness in the community" (Golan, et. al, 2004, p. 14). Middle grade life science students learned as "scientists-in-training" how to pose these experimental questions and translate an inquiry into a research design. Since there are multiple components to this process, it was very likely that students had varying degrees of skill, obtained from previous educational or personal experience. Science teachers and educators are increasingly aware of the need for inquiry-based learning in the classroom if we are to prepare students adequately for success in a technology-based, diverse, globalized society. Teachers are eager to move beyond the limited and misleading textbook presentations of the "mythical universal scientific method" (Cooper, 2004, p. 156). Numerous projects employing technology are furthering the development of learner-driven environments to replace science lessons based on rote memorization. Reiser (2000) described several interactive learning environments, including *Animal Landlord*, a technology-assisted program covering behavior patterns at the middle school level and behavioral ecology at the high school level.

"Guided inquiry" was a term used by the teacher to describe her philosophy about inquiry in the classroom. Guided inquiry seeks to prevent the mistake of allowing students to enter into an investigation where "students enter into a laboratory or field setting wondering what they are supposed to do or see; and their confusion is so great that they might not get as far as asking what regularities in events or objects they are to observe, or what relationships between concepts are significant" (Lazarowitz & Tamir, 1994, p. 17). Being able to relate the purpose of an experiment or research design to the goal or aim of the investigation is related to generating a testable hypothesis. Students in the middle grades showed difficulties composing a hypothesis in the traditional "If, then" format, but displayed the capacity for causal reasoning. This assertion was supported by data obtained from students' work earlier in the semester, at an "International Gorilla Research Symposium." The Dr. Zhivago study demonstrated that students were capable of reasoning about the validity of a data set based on its study length and sampling time.

Cognitive scientists have established a unique and pervading distinction between two types of knowledge related to science. "The term 'learning' is often used in conjunction with the term ‘declarative knowledge’, whereas the term ‘implicit’ is often used in relation to the term ‘procedural knowledge’ because it is not always a conscious application of knowledge, rather it is often expressed through an action or performance. As one gains skill in generating and testing ideas, declarative knowledge acquisition/construction becomes easier” (Lawson, 2003, p. 11). In *The Neurological Basis of Teaching and Learning* (2003), Lawson proposes that learning involves the generation and testing of ideas in a “hypothetico-predictive” (or hypothetico-deductive) format. Failure of observed results to match an expected result can arise from one of two sources – “a faulty explanation or a faulty test… There is a sequence of elements relevant to these events: 1) making an initial puzzling observation, 2) raising a causal question, and 3) generating a possible cause. (Lawson, p. 12). The VG project curriculum supported development of the first two steps of this process.

During the process of investigation, students encountered meaningful behavioral thought processes that were fundamental to the generation of questions, or “puzzling observations,” and assimilated these thought processes with their own mental constructs of how they should think scientifically to reason and infer meaning for what they observed. Students’ reasoning abilities were still in formative states and many types of inquiry questions regarding primate behavior, fossils, and natural selection would initially seem too esoteric for students’ interest to be engaged. The middle grade science student needs a “hook” to focus their attention, such as the audio recordings of gorilla vocalizations, and a sustainable, long term investigation that culminates in a performance assessment product, such as the *PowerPoint* presentation or the research proposal. The broader context for an inquiry-based investigation in science lies in the similarities that correlate scientifically themed investigations across many disciplines and topics. The teachers provided an opportunity to establish standards for these thought patterns that related to science investigations that could be discussed and reflected upon in the classroom. They also provided the “stepping stones” to facilitate a student’s progress from making observations, to drawing comparisons among data sets, and inferring patterns and causal properties. Seventh grade students had the opportunity to experiment with methods for obtaining transformative knowledge that will serve as a foundation for developing the processes of analysis, hypothesis testing, data interpretation and evaluation. They were deeply involved in transformative knowledge, constructed by any process that “more or less directly generate[s] new knowledge” (Gijlers & De Jong, 2005, p. 268).

The VG Project built upon students’ unique research questions related to the use of evidence for investigation into issues of diversity among organisms and human origins. Topics arose through observations, data analysis through comparison, validity, inferences from data, interactive technology and communication of scientific findings that deepened the students’ experience. Additionally, students worked with sensory and tactile applications: data they could see, hear, and touch. Placing gorillas in the classification scheme illustrated variation among organisms and how physiology, morphology, and anatomy affect specific functions. In Lesson 1 and 2 of “What can we learn from skulls?” students examined the anatomy of skulls and teeth and described the forms and functional attributes with labels and field notes in their journals. They compared a carnivore to an herbivore with skull and dentition data and reported their findings. Making these types of observations and comparisons helped to illustrate the increasing complexity of systems in organisms, an essential concept for full appreciation of the variation between species. The concept extended to the idea that organisms possess different forms of similar structures, and scientists create lineage maps based on similarities and homologies between different organism species. In Lesson 3 and 4 of “What can we learn from skulls?,” students observed, drew, and inferred diets of various organisms using fossil evidence, and utilize methods such as the dental formula and unique features of skulls, i.e. angles of basicranial flexion. The anatomy of pelvis, femur, and knee joint further enhanced the supporting evidence for bipedalism. Discovery of the "Millenium Man," a 6-million year old femur bone discovered in Kenya presented a contextual example for discussion. The focusing topics transitioned from brain size and diet to limbs and locomotion. According to Donovan (2001), "Knowing something about the questions that are valued in a discipline can provide insight into both the current state of understanding and how phenomena are reduced to data" (Donovan, 2001, p. 8). Lessons presented with focusing topics and initial questions strengthen students' ability to understand content-related concepts.

Students were active learners and constructed their own knowledge of topics, such as their understanding animal morphology and behavior connected to extant species and those that are extinct. When a form or function no longer supports the activities required for a healthy, reproducing population of organisms, the species does not survive. Middle grades students might have inferred that form and function are directly related to survival of a species. Learning to examine skulls and dentition, and creating individual research presentations involved an examination of the diversity of life on Earth. Answering questions such as "Which of the extant primates is most closely related to *Homo sapiens*?" and "How do features of extant members of a species compare to features of extinct members of a species?" involved "searching for patterns, and comparing patterns found in one group of organisms with patterns found in other groups. . . Specifically, answering questions about the history of life requires analysis of the patterns in fossils, morphological and physiological characteristics of living forms, developmental pathways, behavior patterns, and molecular sequences of nucleic acids and proteins" (Copper, 2004, p. 105). Students were provided an opportunity to investigate several pieces of the puzzle. Reflection on the aligning of teaching goals and objectives for science education focused on the teaching methodology to achieve those aims. Do educators value students that develop individual and unique research questions? Does society promote individuals who seek effective means for solving problems?

The activities of data collection included sketching the skulls in their field notebooks, representations of observed evidence as a basis for forming ideas and conclusions. Students were allowed to choose which skull they would sketch, which provided another opportunity for personal interest to be involved. As the students demonstrated with questions such as: "Are possums herbivores?", "What would you call these teeth?", and "Is it hairy like a gorilla?" the inquiry culture in the classroom encouraged individual inquiry. Questions supported the performance of certain tasks in the scaffolded environment that students would not perform independently, because they required some degree of assistance from peers and the teacher. Often, a peer would assist in constructing knowledge for the group by explaining their reasoning patterns in a most relevant and authentic manner. This "zone of interaction" helped students integrate critical cognitive processes: "The construction zone is an interactive zone where students work together on problems that one of them could not solve individually. Cognitive change takes place within the construction zone" (Gijlers & DeJong, 2005, p. 268).

During the collection of data, students were naturally inclined to categorize and classify. There is an indication that once they classified the organism according to what they already knew, like herbivore or carnivore, they attempted to find other features for further detailing and describing their animal. The gorilla behavior investigation used inquiry to build upon existing conceptual knowledge of animal behavior patterns Students investigated their research question with qualitative data collection and inferences based on the theme of structure relating to function.

Inquiry-based learning requires a systematic supportive network of inquiry-related processes such as evaluating evidence, inferring relationships, and reflecting on research design. The verdict is still out on how students learn to call upon these skills to construct an overall problem-solving approach. White, Shimoda, & Fredericksen (1999) report findings from a study using technology to break down the components of inquiry into manageable stages: "Our claim is that . . . meta-level expertise can be internalized by students and then consciously invoked. . . By internalizing a system of such functional units in the form of advisors, they become accessible to reflected abstraction and conscious control, enabling students to put on different hats and invoke different voices when needed as they solve problems or engage in inquiry learning" (White, et. al, 1999, p. 178). Scaffolding theories describe how assistance to learners allows completion of tasks normally out of reach (Fretz, Wu, Zhang, Davis, Krajcik, & Soloway, 2002). In the study of *Model-It* software, fully three quarters of the modeling practices observed occurred with some type of concomitant scaffolds, such as the software, teacher, or peer. "This is in keeping with the idea that practices have a material aspect where tools and context allow the learner to demonstrate certain practices" (Fretz, et. al, 2002, p. 584). In the VG activities, students completed inquiry processes in the context of a research question and had opportunities to use appropriate tools and technologies. The teacher used questioning strategies to scaffold students' ongoing thought patterns, and specifically helped to relate the purpose of the investigation to the design of the experiment.

Modeling of Scientific Processes

Mental models for using inquiry processes in the biology classroom are supported by the role of the teacher as a curious, question-posing intellectual. By illustrating and further developing research designs to support standards-based content, and attempting to answer related questions, the teacher, guides how students, in effect, "learn how to learn." In the middle grades, science learners are transitioning from the operant definitional stage to a more advanced hypothetico-deductive reasoning stage required for hypothesis construction and testing. Conscientious teacher modeling of the thought processes used by scientists allowed students to compare their own thinking patterns to thinking patterns that generate scientific knowledge. "By modeling a disposition toward inquiry, rewarding creative and critical thinking, and employing technology resources where they are helpful, your class will have richer inquiry experiences" (Coulter, 2000, p. 25). When students explore specific biology learning objectives, such as comparing morphological and physiological characteristics among organisms, they are experiencing one component of science literacy. The data comparison component is integrated into a multi-faceted culture of inquiry learning that includes additional thinking patterns such as inference and reflection. In the development of science process skills, the quality of the investigation into gorillas and fossils had a greater impact than the scope of material covered. Science educators must reflect on the significance of teacher modeling for the mental processes sought after in students.

Since students' learning objectives promoted processes that were relatively new and unrefined, the role of the teacher as a modeler of scientific learning was critical for student knowledge construction of inquiry. The middle school students held partial and incomplete understanding of how to research questions and designing investigative experiments. By incorporating an interactive environment filled with rich discourse and aligning the learning activities with meaningful assessment products, the teacher cultivated a classroom experience that facilitated knowledge construction and conceptual understanding. “Time is required for the description, comparison, clarifying, elaborating and collaborating to reach consensus on specific experiences” (Lorsbach & Tobin, 1992, fr. http://www.exploratorium.edu/IFI/resources/research/constructivism.html). The investigation of gorillas was relevant to organismal structural and functional biology, and expanded on students’ memories of how research and experimental science is performed. Students continually were asked about the research question, to guide their ideas about experimental design. The teacher modeled the skill of analyzing errors, by identifying and articulating how sampling time could be inappropriate for specific studies of gorilla behavior. She modeled the skill of constructing support for an assertion, frequently utilizing the phrase, “but as a scientist, can I say that?,” meaning, “Do the results support my conclusion?” The incorporation of students’ unique research questions introduced students to the skill of integrating personal interest with objectivity regarding different types of gorilla behavior and different fossils. Students developed research questions as a major goal of their investigation. They learned to develop and cultivate questions related to the science of animal behavior and morphology. Their focusing topics and guided questions are similar to the “active situational cognition” described by Scott (2003) as part of a veteran teacher’s inquiry practices: 1) situating instruction in authentic problems, 2) promoting importance of grappling with data, 3) fostering collaboration of students and teacher, 3) connecting students with the community, 4) modeling behaviors of a scientist, 5) fostering ownership by students” (Scott, p. 10).

For true scientific inquiry, students must construct knowledge of how to “propose explanations based on the evidence derived from their work” (Anderson, 2002, p. 2). The most meaningful inquiry derives from authentic questions that are generated from student experience. Students watched video clips of gorillas, observed live gorillas at the zoo, listened to gorilla vocalizations, graphed data, gathered data from skulls and bones, modeled gorilla behavior with emergent technology, and then generated their own research questions based on their experiences within the framework provided. One advantage of the VG project is that students were focused on types of observations and interpretations that expert primatologists use in published research, and the scientist-designed ethogram merged new ways of thinking about observations and animal behavior with a subject animal of familiar morphology. The term “unpacking” (Wandersee, 1994) refers to a framework for “accessing prior knowledge and existent concepts, building tentative bridges and connections between concepts, and importing new models and analogies for reforming, refining, and expanding on their conceptual knowledge base (Wandersee, p. 192).

Since many students displayed interest in species similar to humans, primates help captivate attention for investigating interactions among individual behaviors, group dynamics, and population dynamics. Much is known about the variations in the social group dynamics and life-history patterns of apes, including mountain gorillas, but the biggest remaining gap in our knowledge concerns western gorillas. (Yamagiwa, Kahekwa, & Basabose, 1999; Robbins, Bermejo, Cipoletta, Magliocca, Parnell, & Stokes, 2004). Topics that are incompletely understood by scientists made the classroom investigation authentic. The learning tasks were enhanced with both the real world authenticity, and the responsibility placed on the student for producing “performance” assessments that incorporated written communication, a research proposal, and a *PowerPoint* presentation at a “scientific symposium.” These factors contributed to the development of problem-solving strategies and involved students in metacognition, deductive, and inductive reasoning patterns. Students thought about the methods they used to approach a specific problem or question, used organizational strategies for information and research, analyzed and inferred ideas about animals and fossils they studied, and created a product to develop reasoning about their findings. Further support for the inquiry-based learning strategies included the use of hands-on, sensory experience. The teacher felt strongly that students must see and even hold the evidence they are being asked to construct ideas from.

Students' learning of scientific inquiry processes

Description and Observation

Science as a discipline is built on observation. "Making time for observations provides students the chance to become experts at questioning, hypothesizing, and predicting because all of these flow from observation" (Mackenzie, 2001, p. 4). Science learners must cultivate their accurate observation skills from the beginning, and develop the ability to interpret familiar patterns as "entities." To draw firm conclusions students had to notice important details and record any conjectures or possible explanations during the analysis phase. Students' participation in the data collection is evident by questions that regulate the quality and quantity of data being collected, indicating a concern for accuracy. During the sketching activity, students worked in groups of three to five individuals and asked each other questions as they handled and positioned the skulls:

"How do you draw a side view of this?"

"Do you see the canines?"

"Should we put down the scale?"

"Do we have to draw, like, the teeth?"

“Which ones are the premolars and which ones are the molars?”

The last question provokes a stimulating response from the teacher, who states: “As a scientist, you decide.” Mackenzie (2005) emphasized the need for biology notebooks to be filled with “scientific reports but also detailed observations, sketches, and charts/graphs based on observations made throughout the year” (Mackenzie, p. 70). Teachers should assist with modeling rich description and supplementing observation data. Tabak, et. al, (2003) recognized that science teaching should focus on the types of observations and interpretations that biologists use to explain phenomena. Mental models of procedures and methods to perform are necessary, and must be assimilated into students’ cognitive structures.

Several domains are associated with inquiry-based learning. Multiple components of both data acquisition and its subsequent analysis and interpretation involve reasoning strategies and development of particular inference skills. Students were capable of collecting data in the form of descriptions and observation, and the data they collected provided support for the notion that middle grade students are capable of making accurate portrayals in scientific language of what they observe in the classroom. “The actual process of data collection and manipulation of data allows students to internalize or give meaning to the numbers in a database. In essence, they acquire a ‘feel for the data’” (Gerber & Reineke, 2005, p. 150). The VG project used an ethogram to represent qualitative observations in a database with quantitative numbers. Each student could integrate different approaches to inquiry-based processes, akin to the “diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (Anderson, 2001, p. 23). Students derived their own explanations for gorilla behavior during their research and revealed their ideas in the research proposal. Research questions about morphology and bipedalism were derived from students' interpretations of fossil evidence.

Another influential factor of real data collection is the emergence of questions in a natural and causal manner. Cooper (2004) discovered important features of students' "analysis of patterns in fossils, morphological and physical characteristics of living forms, developmental pathways, and behavioral patterns" (Cooper, 2004, p. 158). The generation of questions that begin with "Who, what, how and why?" was revealed by students' *PowerPoint* research presentations. The "second level inquiry" questions that ask "why" or "how" suggest that students have begun to seek answers to their questions by searching for patterns, and comparing patterns found in one group of organisms with patterns found in other groups. The ability to generate questions about the gorillas, the fossils and skulls, and extinct or extant organisms is evidence of a healthy curiosity that needs to be supported, developed, and refined. Golan, et. al, (2004) studied participants in the *Animal Landlord* with a coding scheme that included "careful observation," "mindful application of categorization scheme," and "articulating evidence." (Golan, et. al, p.12). The students were working with different components of the research process in a complete representation of how the components are directly related to each other. The observations are part of a representative coding scheme that provides explaining and supportive evidence. The experience of making observations enhances students' conceptions of the scientific process, and is a key advantage of asking students to investigate their own questions. They further their understanding of how the process of observing helps to explain why certain procedures were followed. "It is important to explain that notes should be taken on things that may not seem important at the time, because significance of a particular observation may not become apparent until it is coordinated with other observations and a larger picture is developed.

It also introduces the theme of working inductively as new ideas and findings emerge through working with gathered data" (Ostrower, 1998, p. 59).

Comparing and contrasting data enhances the ability to make inferences

As students constructed their own controlled comparisons and generated findings from their own data they intuitively compared behavior patterns across different species in scientific reasoning patterns. The students' presentation of their research projects provided a relevant example of how students followed the proposed framework of cognitive processes during a research investigation.

Initially, the performance task was introduced, so that students knew they would be responsible for producing a presentation and actually sharing the knowledge they constructed during the unit. Then skulls were introduced into the classroom as evidence that could be seen and handled. Various skulls presented the opportunity for students to notice key structural differences related to different species. When the skull of *Homo sapiens* was compared to the skull of the Neanderthal, the modern human skull had a more upright forehead, less protrusive jaws, smaller brow ridges, and a slightly smaller cranial capacity. Some students noticed these features and made descriptions in their field notebooks. Conducting a significant comparison between a carnivore and an herbivore facilitated identification of features related to diet and dentition. The students were encouraged to develop the details by identifying, labeling, and again constructing comparisons between their data sets. Finally, the communication between groups provided informal self-assessment, because students asked themselves, "What did I discover through my analysis of the skulls and the teeth?" and developed the skill of reflecting on their findings.

Students' learning activities culminated in the task of investigating current hypotheses and predicting possible explanations for why bipedalism evolved. The guest teacher asked students: "Why is it faster to walk or move on two limbs?" and lead students to discuss the concept of food gathering, caring for offspring, and using hands to use tools and weapons. A student volunteered a related concept to the discussion: "What about human communication?" The student formed a connection in their mind with free hands and the ability to signal and make communicatory gestures. The question provided an example of a student-generated opportunity for the teacher to assimilate into a research question, or redirect the investigation and clarify its focus. Obtaining evidence for this comparison and making knowledgeable inferences will result in distinct ideas regarding why animals evolved with certain modes of locomotion. The focus of research questions is coming from the introductory class discussion about bipedalism, feeding, offspring, and hunting.

As discussed previously, collected data must be analyzed for its meaning to come to light and for students to learn about the true nature of science. Being engaged in analyzing the relationships of organisms based on critical evidence is an essential component of developing bioliteracy. We need to engage them in the final stages of analysis where meaning is drawn from data, through appropriate scaffolding that prevents overwhelming students. Unfortunately, the portrayal of science as a world of hard and fast facts has influenced students and teachers to occasionally assume that procedures are rigid and answers are "black and white." Real scientific knowledge is obtained through a continually evolving process of trial and error, adjustments, flexibility, hypotheses, and is constantly subject to interpretation and reevaluation.

The connections among concepts required in biology are improved when students relate incoming knowledge to concepts they are already familiar with and have prior experience. These connections were improved during classroom observations when students reflected and reviewed prior research they had done, and wrote research proposals that described their research background and included topics such as DNA extraction, plant tropisms, and frog dissection. With reflection, hopefully students could assimilate the types of research questions that have been asked throughout the year, and develop ideas of appropriate researchable questions that lead them to compose their own question. Comparing their previous investigations with those in progress made previous knowledge applicable to the new research question in terms of how to design the investigation and what kinds of data to collect.

Students make inferences from their data analysis

Following observation and descriptions of gorilla behavior obtained at the zoo, the student confronted a critical component of the research task, the task of analyzing and "grappling" with the data obtained from the "experiment." The reflective process made data collection meaningful, and without a relatively introspective and conscientious interpretation of data, the opportunity for true knowledge would have been lost. A central aspect of the reflection is relating back to the initial research question and learning goals. "Students often go back and change their explanations after having many experiences messing about or collecting evidence. They begin to see that a question is a bridge between what they know and what they don't know, or want to know" (Mott, 2000, p. 12).

The learning environment for the bones and skull investigation contributed positively to students' views of themselves as scientists who must obtain data and analyze their data to make inferences about animals and hominids. They were working with only bones, one source of evidence, and were being asked to perform an investigation into functions and features of organism behavior, diet, physiology and the implications of that information for relating to more far-reaching biological concepts such as structure relating to function and natural selection. Transitioning from procedural knowledge to transformative knowledge is often associated with descriptive investigations that characterize a particular scientific phenomenon. The investigator may expand on the initial descriptive reporting to include an objective inquiry to answer a “who” or “what” (1^{st} level) or “how” or “why” (2^{nd} level inquiry) question. Examples of students’ 1^{st} level inquiry questions include: “What are the similarities and differences between A. afarensis and H. sapiens?” Description of the natural world, especially organisms, could facilitate the generation and testing of questions to develop research investigation. Keys (1998) found that 11-year-old children often choose to undertake descriptive investigations that document natural phenomena when given choices about what they wish to investigate, rather than experimental investigations. Students must learn how to describe their phenomena meaningfully, before they make inferences.

In the classroom, students learned to collect and interpret data with graphing, writing, note-taking, and communication of findings. Following the data analysis of skulls and teeth, students made inferences from skulls of extinct fossils in the context of an investigation into human origins. They examined extinct fossil skulls of *Australopithecus afarensis*, *Australopithecus boisei*, *Homo erectus*, and *Homo neanderthalensis* for making observations, sketches, and descriptions. Here, the canine teeth of gorillas were relevant evidence, in addition to the molar surface area as a dietary indicator. Size and number of teeth, smoothness, roundness and size of jaw are all significant features for the focusing topics regarding dentition and diet. Combining evidence from teeth, brain size, the sagittal crest, skull size and brain capacity, there is a substantial basis for inferring significant concepts such as diet, lifestyle, cultural history and biological evolution of hominid species. Again, teachers posed guided questions during these activities to emphasize and focus the investigation on content of the data collection and inferences to be made from students' data collections. The guided research question, "What are the advantages and disadvantages of bipedal locomotion compared to quadrapedal locomotion?" was the focusing research question.

Evaluating dentition as one piece of evidence, angles of basicranial flexion as another piece, and hip and femur bones as a "clinching" piece of evidence supports inferences about bipedalism. This concept of clinching evidence, or a piece of the puzzle that makes the whole puzzle suddenly clear, is an important characteristic of scientific conclusions. "Most scientists would accept as fact (inferential fact) that a fire had occurred in an area if several observations pointed, convergently, toward a fire. . . Perhaps none of these observations was convincing by itself…Convergence of evidence is the clincher" (Kinraide & Denison, 2003, p. 419).

Reflection enhances the rich environment required for inquiry

Reflection on the research process is required for true integration of scientific processes with existing knowledge structures. "Students internalize the process of inquiry as one of proposing conjectures and evaluating alternatives more easily after these processes have been practiced in a group context" (Tabak, 1995, p. 2). The process of constructing knowledge is supported and developed through evaluation, refinement, and communication. Interactions and discourse enhance conceptual understanding, which leads to increased curiosity and posing of questions. "Our results support the prediction that the frame of reference for making self-evaluations will be affected by the performance of peers in the immediate social context" (Stetcher, 2000, p. 371).

The communicative processes required of all scientists are exemplified by student activities such as reflective writing, writing research summaries and proposals, presentations, and the interaction between students within the Virtual Gorilla learning environment. Clearly, the supportive environment increased levels of discourse and provided stimulation for investigation and questions. The nature of human behavior includes a need to fill in the gaps in one's knowledge, and the environment serves a powerful stimulus by making students' aware of their need for knowledge, but also providing tools and scaffolds to support true knowledge construction. By increasing the level of communication between students, activities provide necessary reflection. If a student must talk about a concept, there is less room for misconception and miscommunication. The student must clarify their understanding of critical concepts in an environment that values scientific knowledge. The distinction between procedural knowledge in science and transformative knowledge associated with inquiry and scientific investigation was described by Lawson in an interview: "According to Piaget's theory, the development of procedural knowledge occurs as a consequence of both physical and social experience, neurological maturation, and self-regulation. Self-regulation occurs when self-generated ideas and behaviors are contradicted. These contradictions lead to not only new ideas and behaviors, but also to improved reasoning abilities" (Cardellini, 2005, p. 141). Content knowledge aids reasoning abilities when a student is familiar with an idea, and therefore it is easier to describe that concept amongst peers and teachers.

This study notes the significance of students' interactions amongst each other and with the teacher during the learning process. The level of discourse, or discussion that occurs in the classroom may serve as an indicator of students' reasoning skills. "A visitor to your classroom would see students working together collaboratively, actively engaged in designing inquiries, collecting data, synthesizing ideas, and explaining their results or building concepts. You ask higher order questions and have many ideas and skills to share" (Leonard, 2005, p. 75). Fretz

(2002) describes the “creation of **self-explanations** and the **cognitive conflict** that often arose in learner pairs are both important in developing an understanding of the content of the model and the modeling task” (Fretz, p. 584). The interpretation of student utterances helped make informal thinking visible, and established the basis for students’ conceptual understanding.

Students reflect on their research design as they collect data and comparing choices in an empirical investigation scheme. The observation-based data collection activity at Zoo Atlanta served to encourage discourse where students justified their choices within the ethogram. Questions like the following occurred between student partners while they collected data at the zoo:

S1 Why do you always put solitary when it is moving?

Frederickson & White (1997) found that reflection served two processes in students’ inquiry-based learning: 1) reflection on goals entailed in carrying out problem solving, and 2) reflection on the intellectual processes involved in implementing those goals (Frederickson, 1997, p. 54). The process of critical thinking benefits from students’ verbal and written expressions that facilitate teacher feedback. Scientific writing is a crucial component of developing communication skills involved in authentic science. Krueger & Sutton (2001) described how individual self-evaluation through “reflection pieces, scientific goal-setting, record keeping, journaling, and writing in science personalizes the activity for the student” (Krueger & Sutton, 2001, pp.38-39). The importance of writing was not underemphasized and taught students to organize, to convey, to question, to conclude, to defend, and to enhance the conversations and discussions with their peers. Students’ daily notes and observations into their field notebooks, research proposals, interpretations of their graphs, and *PowerPoint* presentations about animal behavior, morphology, and hominid evolution reflect positively the development of writing abilities to describe both evidence and conclusions.

Technology in an inquiry-based classroom

Technology improves interactivity between students and data

Students used technology to communicate more clearly and investigate more deeply in order to further their own knowledge. Understanding of other students' work further enhanced student learning because it improved communication skills and motivated students to contribute to the "scientific community." Once students had experience constructing their own graphs and interpreting procedures, they were in a position to achieve further development of communication standards such as being able to "question scientific claims and arguments effectively," especially those "based on vague attributions (such as "Leading doctors say...")" and to "identify the flaws of reasoning that are based on poorly designed research (i.e., facts intermingled with opinion, conclusions based on insufficient evidence)" (GPS, retrieved June 2005 fr. http://www.georgiastandards.org/science.asp). Especially evident in this study was the improved ability of students to question the value of arguments based on small samples of data, as a majority (80%) of students explained why a 20-minute study was too short to accurately represent the conclusions that were drawn in Dr. Zhivago's study. Interactivity in the classroom was improved as students gained confidence in their scientific abilities and were able to develop questions and commentary during lessons.

Technology as a realistic tool for constructivist learning

The inquiry process allowed students to experience how actual data and notes are presented for analysis and interpretation. They also constructed knowledge regarding how a graph's appearance correlates to the data it represents. Analysis of students graph revealed that some had a high percentage of just two or three behaviors, and no data for the other behaviors. Graphs provided a visual representation of the data that is relevant for most styles of learning. Quantitative representation of stationary behavior compared to other forms provided an opportunity for students to manipulate their numbers and tally marks into graphical representation that generated more meaningful discussion and more valuable interpretations by the student, classmates, and teacher. Graphing behavioral data is one of the simplest ways to visualize complex principles regarding ethnography and primatology. Educational application of the tools such as satellite and video field imaging may be combined with real time zoo data to turn students into animal scientists. Coulter (2000) illustrated the underlying principle behind technology use in the classroom: “Video serves an important role in bringing students to distant places, but it is up to the teacher to ensure that the rest of the curriculum supports significant inquiry as the core of the experience” (Coulter, p. 24). Motivation and skepticism were benefits of the rich science learning environment. The rich learning environment hinges on students’ and teacher’s ability to make relevant conceptual connections and generate transformative knowledge.

Scientific studies can be simulated with computer models and data collection in the classroom, and supplemented with additional information supplied through both teacher and student research. Using a spreadsheet program, such as Excel or Lotus, allows the teacher to become familiar with an extensively supported technological format and learn of its variable and flexible use for scientific data collection and display. Extensive data sets may also be downloaded from credible sources online and improve the level of discovery and data analysis. Additionally, some graphs are already constructed and may be downloaded without any additional assistance. Principles can be illustrated using demonstrations and models, and reinforced when real data is collected and students are able to link between what they are learning in the classroom and how evolutionary biology data is collected and analyzed in the real world of research. The same phenomenon may be examined with multiple representations, such as with a bar graph, histogram, scatter plot, or with computer simulation. Students are more prepared to relate academic and occupational endeavors and projects to their current role as a student of science. Actual data from the animal's natural or simulated habitat is easier to relate to the principle of animal behavior and related biological themes.

The use of the Motion Modeler provided significant insight into the use of modeling technology in the biology classroom. Teachers' use of models depends on their understanding of the model's capability to reinforce content objectives. In a study of prospective science teachers (Cullin, 2003), all agreed that it is important to teach about models and modeling. "However, it was interesting to analyze their responses to whether or not they would *actually teach* about models and modeling in their own future classrooms" (Cullin, p. 419). The study explained that there was little mention of the central role of models in the development of scientific knowledge (Cullin, p. 420). The Motion Modeler provides an example of how students used an emergent technology in the classroom to support the concept of models representing a natural phenomenon in a computer-based system that will accept user input and generate resulting output in accordance with the design of the model. Students led the discussion of their ideas to improve the software. Students' ability to recognize the limits of the model, such as a lack of facial expressions on the gorilla, is an understanding of the nature of scientific investigations. Scientists use models to represent organisms, species, populations, systems, and predict scenarios such as global warming where a variety of factors are intricately coordinated.

Benefits of completing the learning cycle with various cognition methods include more complete science knowledge construction: “Each learning task will consist of a cycle of prediction, observation, and explanation. We are manipulating the visual, tactile, and auditory cues that students receive to assess the utility of the multisensory experience” (Salzman, 1994, p. 8).

The Biological Sciences Curriculum Study (BSCS) illustrates the potential of technology-based projects in the classroom: “Give students an appreciation for careful quantitative observations, application of inductive and deductive reasoning, experimental controls, and the fact that conclusions in science are tentative, and they learn the need for suspended judgment.” (Metzner, p. 35) An interesting result from Cuevas’ study of students’ abilities to perform inquiry reinforces the idea of “stepping stones” used to take students from a problem to a solution. The study found that students’ ability to formulate a problem statement did not improve significantly, but their ability to develop procedures for solving the problem improved significantly. (Cuevas, 2005, p. 348). Technology was one component of the rich, inquiry-based learning environment, and provided scaffolding for students’ thought processes. However, the technology used was but one component of the overall framework developed by the teacher for implementing inquiry into the biology unit on gorilla morphology, behavior, fossil evidence, and natural selection.

Implications

Aligning learning objectives and assessments

Curriculum, instruction, and assessment are interconnected and correlated. When learning objectives are clearly aligned with performance tasks, students assume more responsibility for their input into the classroom and become more reflective on their progress. Students’ questions regarding their research field trip, i.e. Can a gorilla exhibit more than one behavior at a time?, and evaluations of the validity of their collected data appeared to support this assertion. The research activity and *PowerPoint* presentation required students to present what they learned as part of an International Research Symposium, and removed any distinguishable barrier between teaching and assessment. Students were expected to provide a clear explanation of their achievement of learning objectives that illustrated students' conceptual knowledge, unlike a numeric test score or percentage that does not present an authentic representation of conceptual understanding. Characteristic habits of mind that scientists use to investigate and communicate were revealed with process skill objectives from the Georgia Professional Standards Commission (Georgia Performance Standards, retrieved June 2005 from http://www.georgiastandards.org/science.asp):

CTSh3. Students will identify and investigate problems scientifically.

CTSh6. Students will communicate scientific investigations and information clearly.

CTSh8. Students will understand important features of the process of scientific inquiry.

There was strong support for students' initial understanding of the nature of science, although their overall understanding of the research design was unclear. The ability to draw comparisons, make inferences, and investigate organism diversity will support students' achievement of the learning standards for the county, including the following content objective:

SB5. Students will evaluate the role of natural selection in the development of the theory of evolution.

Students assumed responsibility for both data collection and the transformative mental process of inferring ideas, concepts, and relationships from the data. Asking students to be gorilla and fossil investigators in the classroom required the student to make sense of the data, as opposed to the curriculum materials or the teacher interpreting the data for the student. A significant portion of the learning standards for life science is devoted to the ability to communicate clearly, including the ability to "write clear, step-by-step instructions for conducting particular scientific investigations, operating a piece of equipment, or following a procedure," and "write for scientific purposes incorporating data from circle, bar and line graphs, two-way data tables, diagrams, and symbols" (Georgia Performance Standards, retrieved June 2005 fr. http://www.georgiastandards.org/science.asp).

The needs of teachers for standards-based science teaching and student learning must be considered when implementing inquiry-based curriculum. Marx (2004) described the success of a systemic reform context for obtaining positive results. "Assessments were used that were aligned with curriculum materials and the district's curriculum framework. A professional development program was designed to engage teachers in the intensive learning needed for them to change their practices and support standards-based, inquiry instruction" (Marx, p. 1073). Significant time and resource investment facilitate the alignment of inquiry standards, authentic scientific practice, and classroom learning. The county curriculum provides a supporting framework for inquiry process skills with the learning objectives for 7th grade life science. Students are to learn how to design and experiment, how to record and display data, how to communicate knowledge generated, and to know that the processes of inquiry, experimental design, investigation, and analysis are as important as finding the correct answer. Student learning with the Virtual Gorilla builds upon what students have learned of animal behavior by developing guided inquiry activities that correlate primatologist research to the scientific process skills and fundamental themes of biology. Emphasis on conceptual knowledge, hands-on experience of data collection and analysis connected to authentic assessment created a rich learning environment for knowledge acquisition.

Various tools assisted students' collecting data on gorilla behavior and fossil evidence, as part of a learning environment that provided scaffolding for learning about gorilla biology, fossils, and organism diversity. Greenler (2004) described a "problem space" as a "way of organizing diverse kinds of information and tools to support inquiry" (Greenler, p. 1). Their learning environment combined biological principles with analysis tools and data sets to provide uniquely constructed learning opportunities that depend on the students' level of cognition. In the classroom, the magnification formula, a tool for describing the actual size of a represented model, the dental formula, the gorilla vocalizations, the "Motion Modeler," and other assistance was provided for representing and organizing data. Little or no prompting was needed for students to incorporate both the dental formula of their fossil and the magnification into their field notebooks. Positive effects from aligning the process skills of designing a research investigation included the ability to derive explanations from evidence, and may have correlated with the use of these types of supportive tools in the classroom. The learning standards required students to use tools for observing, measuring, and manipulating evidence, including appropriate technologies, and students' graphs, proposals, and presentations demonstrated success in this area. The data suggested that students' focus on listening more productively to the teacher's instructions for taking notes and using technological tools when they are responsible for creating a product with the technology. The advantages of educational technology as a learning tool for controlling experiments, collecting experimental data, and constructing graphical representations and statistical analyses of data are unrealized in the science classroom. Additionally, novel emergent technologies such as the Virtual Gorilla Motion Modeler, offer teachers an avenue of presenting improved ways of thinking about science, so that students have an opportunity to view the same phenomenon of study in multiple representations.

Students’ abilities to learn with inquiry-based curriculum methods in a classroom model of a research community was evident from this study and encourages the use of current scientific research to stimulate interest and inquiry amongst middle grade students. Gorilla biology, forensics, global warming, human origins, infectious diseases are just some examples of topics that provide ample material for designing engaging scientific investigations. Inclusion of technology in the curriculum will depend on how readily students’ learning is supported by the technology itself. “We need studies to investigate how simulations and modeling environments can be designed in order to effectively support student learning. Such studies might focus on interface and data representation techniques that prove to be the most useful, accessible, and engaging to students and teachers . . . Finally, we need studies which examine the relationship between data collected in real world and data generated by simulations or student-created models, in order to sort out issues of model accuracy, validation, and usefulness” (Stratford, 2005, p. 20). Teachers are essential in gauging the level of students’ responsiveness and their conceptual understanding of the learning objectives.

Scientific Context

Modern scientific research moves in a relentless, complex, interdisciplinary manner and utilizes a wealth of information and data under constant review, analysis, refinement and revision. Scientists solve puzzling questions by putting together pieces of information in what can appear initially to be abstract relationships. Later, abstract relationships that receive support and evidence can be solidified and complete knowledge is advanced. Scientists now know that humans who “looked like us had evolved by 195,000 years ago, as evidenced by Homo sapiens from the site of Omo Kibish in Ethiopia” (Wong, 2005, p. 88). But fossils cannot paint the entire picture of human evolution, as cultural remains and anthropology provide indications of modern thinking that are amazingly abundant after about 40,000 years ago.

As a species, *Homo sapiens* represents a small portion of the hominid lineage, since remains date back 160,000 years ago on the geologic time scale. The earliest ape species dates back over 20 million years ago (Stringer, 2005). Scientists face an enormous challenge in reconstructing evolutionary lineages of the numerous ape and human-like species that existed in the interim. The search for human origins seeks out fossil skulls such as those of extinct *Australopithecus afarensis*, *Homo erectus*, and *Homo neanderthalensis* as evidence to infer relationships between these species in a evolutionary tree. Fossil evidence supports the sequential appearance of ape ancestors in the following order: Proconsul → *Australopithecus* → *H. erectus* → Neandertals and *H. sapiens*. Additional discoveries of *Homo floriensis* in Indonesia and the latest finds in Gran Dolina, Spain add new evidence and theories to the investigation. Bipedalism is supported by evidence from the skulls, dentition, basicranial angle, pelvic girdle, and femur bones. Scientists propose numerous advantages that bipedalism offered to human ancestors, such as efficient locomotion, free hands for making tools, using weapons, carrying food and offspring, the ability to see prey and predators over tall grass, and the ability to travel and migrate across land. Rich, descriptive comparisons will further enhance the culture of learning in the classroom and help students to pose logical questions for independent investigation. Beyond just human evolution, study of early hominid evolution provides insight into the nature of scientific discovery.

Humans are classified as *Homo sapiens* based on habitual and striding bipedal locomotion. Bipedalism is a form of locomotion with an uncertain origin and resulted in major consequences that affect hominids' survival rates (Stringer, 2003). Four adaptations of modern humans are related to bipedal locomotion: upright walking, reduced size of front teeth and enlargement of molar teeth, cultural evolution, and a significant increase in brain size. The three early hominid species are included in the genus *Homo*, and demonstrate additional distinguishing characteristics besides bipedalism. Scientists, including anthropologists, have supported the notion that key advantages related to bipedalism are related to "essentially human" activities, such as the ability to carry things like food, and the ability to manipulate things like tools and weapons. For scientists to evaluate the intelligence of early species, distinguishing between cultural and biological evolution has become a major part of the game.

Researchers are also making numerous discoveries about the origins of human behavior that distinguishes this species from all other hominids, and conduct detailed analysis of locomotion, the migration of apes from Africa, the use of symbolism and art, and the use of tools. The investigation into human origins blends biological evolution with cultural and behavioral elements. New findings indicate that our species had keen intellect and that the cultural evolution of human society began much earlier, more than 50,000 years earlier than previously believed. (Wong, 2005) Elements of modern human behavior that have recently received considerable attention include the use of symbolism, cooperation and sharing of resources in the face of ecological disaster, use of projectile technology, population growth, and brain mutations.

Goals of Science Education

There is a critical period of learning for students of science, where a transition from strictly procedural knowledge and rote memorization to purposeful investigations worthy of contributing transformative knowledge towards solving problems. This transitional learning period must occur if the cognitive processes of scientific thinking are to be integrated as a functional pattern of thought. Considered within the context of individual conceptual change, the correlation between “splashdown and attitude changes meant that students with lower splashdown scores tended to decrease in motivation and confidence during the follow-up period, just as students with higher scores tended to increase” (Stake, 2005, p. 371). Positive learning experiences would serve to increase both students’ motivation and confidence in problem-solving and critical analysis.

Many factors contribute to the successful use of hands-on learning in science, including curricula, resources, learning environment, teaching effectiveness, and assessment strategies (Lazarowitz, 1994). These factors combine to form a powerful influence on students’ thinking patterns. The need for students’ complete understanding of science as a “mode of investigation which rests on conceptual innovation, proceeds through uncertainty and failure, and eventuates in knowledge which is contingent, dubitable, and hard to come by” (Schwab, 1962, p. 5) could not be overemphasized, as the pace of scientific and technological advancement has established a global context and precedent. This idea is critical as it serves to provide key initiative and interest in discovering the answer to THEIR question, rather than someone else’s pre-determined question. Meaningful knowledge construction in science improves when students’ are involved in realistic inquiry investigations that include authentic assessments, interactive technology tools, teacher scaffolding, and questions of interest to the student.

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