

RECONCEPTUALIZING PEDAGOGY AS MIDDLE SCHOOL STUDENTS APPRENTICE
AS PALEOANTHROPOLOGISTS:
EXPLORATIONS IN EVOLUTION AND THE NATURE OF SCIENCE

by

SERI CHAPMAN BEALL

(Under the Direction of Norman Thomson)

ABSTRACT

My study (1) investigated the views and abilities that emerged when 7th grade students apprenticed as paleoanthropologists using 3-D, extinct, hominin skull replicas, (2) explored how my conceptions of the teaching and learning of human evolution changed as I engaged in teacher research, and (3) produced recommendations for an improved, empirically based, human evolution curriculum after an analysis of student and teacher data. Teacher research framed my study, as the data emerged from the organic setting of my 7th grade life science classroom, emancipating both teacher and student voices with the intention of influencing other concerned practitioners and policy makers. The prolonged and privileged access to my research setting provided flexibility in implementing a comprehensive, three-week curriculum intervention, rendering a rich data set toward trustworthy and viable findings.

The curriculum design concept of backwards design drove all teaching and learning toward capstone events—students approximating the work of expert paleoanthropologists to recreate hominin life histories and phylogenies. Two scaffolding units (one developing normative views of the Nature of Science, and one developing skills in the art of observing extant mammalian skulls to infer life histories) provided frameworks for subsequent inquiries during the human evolution unit. This study provided important insights as the first study to empirically measure outcomes of a human evolution curriculum with middle school students, and through the lens of teacher research.

INDEX WORDS: Paleoanthropology, Hominin evolution, Human evolution, 3-D hominin skulls, Middle school education, Science education, Evolution education, Teacher research, Inquiry-based learning, Situated learning, Backwards design, Nature of science, Understanding, Knowledge

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DEDICATION

I would like to dedicate this dissertation to my husband Brent, and to my two sons, Bryce and Bridger. I want to thank Brent for supporting me through this endeavor both emotionally and financially. I want to thank Bryce for his spontaneous curiosity, helping me to rekindle my own wonder of the natural world. I want to thank Bridger for his funny ways, endearing giggles, and easy smiles. Last, I want to thank all of you for bringing meaning and purpose to my present and future. I hope the spirit of inquiry and life-long learning present in this study, permeates our future experiences together.

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CHAPTER 1

INTRODUCTION

Decades of research on the teaching and learning of evolution sprinkle the contents of eminent science education journals (Alters & Nelson, 2002). This research focuses on identifying student alternative conceptions (e.g., Dagher & Boujaoude, 2005), measuring the effects of cognitive conceptual change models (e.g., Banet & Ayuso, 2003), and exploring the relationship between understanding, belief, and acceptance (e.g., Sinatra, et al., 2003). One frontier remains untouched—assessing the teaching and learning of human evolution—until now.

My study (1) investigated the views and abilities that emerged when 7th grade students apprenticed as paleoanthropologists using 3-D extinct hominin skulls, 2) explored how my conceptions of the teaching and learning of human evolution changed as I engaged in teacher research, and (3) produced recommendations for curriculum modifications based on the analysis of student and teacher data. The curriculum intervention used 3-D extinct hominin (human) skull replicas as a centerpiece for inquiry. Students stepped into the shoes of paleoanthropologists during situated learning (Lave & Wenger, 1991; Cordova & Lepper, 1996; Crawford et al., 2005; Rivet & Krajcik, 2008; Roth, 1995; Schwartz, Lederman, & Crawford, 2004), reconstructing the stories that the skulls tell us about our human past.

Teacher research framed my study methodologically. Teacher research was appropriate to my study given its unique feature of teacher-researchers constructing knowledge and theory in the organic settings of their classrooms (Cochran-Smith, 2005). A mosaic of curriculum design principles including: backwards design (Wiggins & McTighe, 1999), situated learning (Lave &

Wenger, 1991; Crawford, Zembal-Saul, Munford & Friedrichsen; 2005), scaffolded inquiry (Reise, 2004; Sandoval & Reiser, 2004), explicit Nature of Science instruction (Schwartz, Lederman, & Crawford, 2005) and learning tools (e.g., 3-D, extinct, hominin skull replicas), framed the “big ideas” of the curriculum down to the details of daily learning experiences.

Research Questions

I posed seven research questions, subsumed under either the a) affective domain, b) cognitive domain, or c) teacher reflection domain. One research question was subsumed under the affective domain:

1. What affective outcomes are expressed when students apprentice as paleoanthropologists?

Four research questions were subsumed under the cognitive domain:

2. What student views of the Nature of Science are communicated as they apprentice as paleoanthropologists?,
3. What student abilities of inquiry are demonstrated as students apprentice as paleoanthropologists?,
4. What student knowledge of hominin evolution is communicated as students apprentice as paleoanthropologists?, and
5. What student understandings of hominin evolution are demonstrated as students apprentice as paleoanthropologists?

Two research questions were subsumed under the domain of teacher reflection:

6. How do my conceptions of teaching and learning of human evolution change during the study as I engage in teacher research?

7. How should the curriculum intervention be modified based on teacher and student data sources?

Project Goals

Constructing three publishable documents served as project goals. The first two papers will be submitted to scholarly, peer-reviewed journals and will: (1) discuss the student views, knowledge, understandings, and abilities that emerged when they apprenticed as paleoanthropologists using 3-D extinct hominin skull replicas, and (2) reveal the insights gleaned when I engaged in teacher research during and after the curriculum intervention. The third publication will provide a day-by-day, minute-by-minute curricular scope and sequence for teaching human evolution with 3-D hominin skull replicas, to be distributed by a publishing company such as the National Science Teacher Association for practical application in secondary science classrooms.

Project Contributions

These three documents have the potential to make significant contributions, answering recent calls for empirically based curricula made by the academy. Catley (2006) and Daugher and Boujoude (2005) have emphasized the need for evolution curricula that “take into account *the ways in which scientists operate in their fields*” (Catley, 2006, p. 779). Students in my curricular intervention apprenticed as paleoanthropologists. They learned about evolution through authentic experiences (Roth, 1995) that generated ongoing lines of inquiry (Dewey, 1938) rather than through conventional, more dogmatic approaches (e.g., Jensen & Finley, 1995). My study took on another challenge made by the academy; teach macroevolution (Anderson & Wallin 2006; Catley, 2006; Padian, 2010). The academy has recognized that there is an overemphasis on the teaching and learning of microevolution (changes that occur at the level of

the individual such as mutation or the level of the population such as natural selection). They have contended that holistic instruction includes macroevolution, which combines concepts of deep time, fossils, speciation, extinction, and evolutionary trees (Nadelson & Southerland, 2010a). Studying human evolution encompasses all of these concepts (Cartmill & Smith, 2009). Last, my study can contribute to the paucity of evolution education research that explicitly discusses the methodology, pedagogical approaches, and curriculum design principles employed (Smith, 2010b), and the paucity of research on the outcomes of teacher research (Cochran-Smith & Zeichner, 2005).

Project Significance

My study was the first empirically based study of middle school students learning about human evolution—a surprising phenomenon given that the American Association for the Advancement of Science has set the following benchmark: “By the end of 8th grade, students should know that fossil evidence is consistent with the idea that human beings evolved from earlier species (AAAS, 1993, p.129). Moreover, my study was significant given the perceived conflict between evolution and religion (Scott, 2004), the meager cognitive gains rendered through previous curricular interventions (e.g., Bishop & Anderson, 1990), and the dichotomy that exists among scientists and the public; forty-five percent of Americans “believe that humans were created by God pretty much in their present form at one time 10,000 years ago” (Newport, 2004). According to the science, humans arose six to seven million years ago, and have been evolving ever since (Cartmill & Smith, 2009). Last, my study was significant in light of the most critical issues of our time such as “global warming, population growth with all its attendant demands on limited resources, pandemic threats of virulent diseases, and availability of weapons that can cause massive damage and render parts of the globe uninhabitable” (NRC, 2010, vii.). It

is imperative that we come to know about our own human past, so we can be better informed about our future.

Overview of Theoretical Framework

Social constructivism (Vygotsky, 1978) framed this study. Social constructivism assumes a pluralistic, relativistic ontology; multiple *truths* (emphasis on little *t*'s) exist, lying in stark contrast to objectivism and the assumption of one *Truth* (emphasis on capital *T*). Individuals (e.g. teachers or students) bring various perspectives (e.g. fundamentalist Christian worldview versus naturalist worldviews) and various prior knowledge (e.g. normative versus alternative understandings of evolution) to phenomena (e.g. human evolution curriculum). These initial conceptual frameworks undergo modifications and revisions during the learning process, yet emergent understandings may be quite different among individuals even though participants interface with the same phenomena. Social constructivism also makes explicit the notion that individuals actively construct knowledge in social contexts, which also has implications for the methodology and pedagogy employed in this study.

Overview of Methodological Framework

I used teacher research to methodologically frame my research study. Cochran-Smith and Lytle (1999) defined teacher research in a general sense

to encompass all forms of practitioner inquiry that involve systematic, intentional, and self-critical inquiry about one's work in K-12, higher education, or continuing education classrooms, schools, programs, and other formal education settings (p.22).

More specifically teacher research encompasses the following six criteria as identified in the literature: a) systematic and intentional inquiry, b) organic, c) cyclic and reflexive, d) action

oriented, e) socially constructed, and d) political. My research appropriately met these six criteria.

First, I employed systematic and intentional research methods to render rich description of classroom phenomena. Second, research findings emerged from the organic setting of my public school classroom, and addressed problems/questions derived from this organic setting. Third, my research refined during five years of co-generative inquiry with my major professor, reshaped through self-reflection, and evolved based on input from over 40 classroom implementations and three summer professional development workshops. Fourth, my research embodied action-oriented components as my pedagogical practice changed through experience and reflection, and efforts were intentionally made to influence the larger educational community through publications, workshops and conference presentations. Fifth, my research rendered through socially constructed activity; the success of this project rested on the interdependency and contributions of teacher-researcher, university-based professors, student-participants, and other colleagues pursuing mutual conversation and efforts. Last, political strands of my research included emancipating the voices of teachers and students to influence educational policy, and taking on the central topic of teaching human evolution, which often receives public and political resistance.

Overview of Curriculum Design Principles

I carefully selected a mosaic of six curriculum design principles based on recommendations from the literature review of evolution education. Backwards design (Wiggins & McTighe, 1998) was the main curriculum design principle in my study. Backwards design turns the approach to teaching and learning upside down. Teaching and learning is approached with the end in mind; teachers and learners ask, “What do we want to know and be able to do by

the end of the curriculum unit?” The end in mind in my study envisioned students approximating the work of paleoanthropologists—sharing reconstructed life histories of extinct hominins and hominin phylogenies in simulated peer-reviewed symposia. Authentic assessments were developed first (e.g., students present the evidence for the reconstructed life histories of a hominin fossil find) and in turn provided a driving force for the learning process and a framework for daily instruction. Thus, the “big ideas” of paleoanthropology infused learning, with the intent to engender “enduring value” and “enduring understanding” for students (Wiggins & McTighe, 1998, p. 23).

A subset of curriculum design principles supported backwards design: situated learning, scaffolds, inquiry, explicit NOS instruction, and learning tools. Situated learning (Wave & Wenger, 1991) assumes that learning occurs in authentic contexts. Situated learning in my study approximated the context of paleoanthropology. Learning was couched in the culture, practice, and language of paleoanthropology. Inquiry provided further pedagogical guidance; learners engaged in inquiry, the essential activity of science with “two critical aspects, the process of finding out and the product of the search” (Chiappetta & Koballa, 2006, pg. 144). My students and I made inquiries about our human past, and shared our discoveries with one another. However, our inquiry-based experiences were highly scaffolded by myself as the teacher to provide students with appropriate supports for learning. Scaffolding student learning included setting high expectations for students through essential questions and rubrics, challenging learners to make connections to prior knowledge, providing helpful benchmarks, engaging in sense-making activities, giving frequent formative and summative feedback, etc. Scaffolding inquiry provided a foundation for a more theoretical consideration of science—how and why scientific knowledge is constructed—which is formally coined as the Nature of Science. We

concurrently and explicitly grappled with NOS concepts while conducting inquiry. For instance, we made observations of hominin skull characters, yet also discussed how to make observations, the relationship of observation to inference, and the quintessential nature of observation to scientific knowledge. Learning tools such as 3-D extinct hominin skulls were essential in creating a situated environment, engaging in inquiry-based tasks, and considering NOS concepts such as the tentative nature of science.

CHAPTER 2

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Literature Review

Introduction

This section of chapter two provides a literature review to situate this study. Four areas of the literature explored included: a) public versus scientific views of evolution, b) arguments for teaching evolution and human evolution, c) outcomes of conceptual change and pedagogical approaches used to teach these two topics, and d) the use of hominin skulls to teach human evolution. I explored the larger topic of evolution—even though my curricular intervention addressed human evolution—to provide greater context and because of the paucity of research regarding human evolution education. Exploring the public's view versus the scientific view of evolution was important for understanding the dynamic that arises when these views juxtapose in the science classroom. Because this study centered on the teaching and learning of human evolution, it was also important to explore rationales for teaching this perceived topic of controversy, as well as explore previous curricular attempts and the subsequent learning outcomes. My own study developed out of the findings of these studies and became situated in the literature as a unique study with the potential for useful contribution. This literature review was constructed by combing through major refereed education (mostly science education) journals, and through articles published between 1990 and 2008. A select number of articles prior to this time frame were used if deemed germane to this study.

Evolution and Public Understanding

The dichotomy.

A chasm of understanding exists between the American public and scientists in regards to one of the most important themes of biology—evolution. A recent gallop poll (Newport, 2004) reported that one third of Americans are in agreement with the statement that “Charles Darwin’s theory of evolution is a scientific theory that has not been well-supported by evidence”. The gap widens in regards to human evolution. Forty-five percent of Americans “believe that humans were created by God pretty much in their present form at one time 10,000 years ago”. Scientists, on the other hand, see evolution as the most logical, evidence-based explanation for the diversity of life on our planet as displayed in the fossil record and through the varied genetic, molecular, behavioral, and physical characteristics of extant taxa (Mayr, 2001). And according to the science, humans arose six to seven million years ago.

Moreover, Darwin’s theory of natural selection has been subjected to scrutiny by the scientific community for the last 150 years, only to be substantiated with further evidence (e.g., modern genetics), augmented by other theories (e.g., genetic drift), and corroborated in various fields of science (e.g., geology, paleoanthropology, ecology, biochemistry, and genetics). The case for human evolution has also strengthened with the discovery of new hominin fossils (e.g., *Australopithecus sebida*) and the development of sophisticated dating methods (e.g., argon dating), and the science of molecular clocks (Motoo, 1968). Science, however, does not go without healthy doses of disagreement; scientists sometimes disagree about *how* evolution happened, but not *if* it happened. So, the science of evolution is robust and built along multiple lines of evidence—collectively referred to as the evolutionary synthesis (Mayr & Provine, 1998).

Dichotomous views in spite of leadership, standards, and interventions.

Dichotomous views among the American public and scientists persist in spite of leadership, standards, and intervention from the education community. Ninety-two scientific and scholarly organizations and 52 professional organizations promoted evolution education (NCSE, 2008). National standards and benchmarks of science followed suite. The National Science Standards identified evolution as a unifying theme to be utilized as a framework for learning throughout k-12 instruction (NRC, 1996). A more specific scope and sequence for how to do so was outlined in the Benchmarks for Science Literacy (AAAS, 1993). Beginning with kindergartners, concepts of diversity and extinction can lay a foundation for future inquiries in secondary school dealing with more abstract concepts—molecular evidence, mutation, natural selection, genetic drift, and deep time. Discussion of human evolution can even begin in middle school; according to the Benchmarks, middle grades students should know that “Fossil evidence is consistent with the idea that human beings evolved from earlier species (AAAS, 1993, p. 129). Researchers have implemented curricular interventions based on these standards, but with minimal success; students continue to display alternative conceptions (e.g., Bishop and Anderson, 1990). Some interventions have shown increases in student understanding, yet produce little to no changes in acceptance or belief (e.g., Demastes, Good, & Peebles).

Why the dichotomy exists.

A complex network of factors influence non-scientific views of evolutionary theory. First, evolutionary theory is difficult to teach and learn. Learners continue to demonstrate alternative conceptions in spite of sound instructional interventions, biology coursework, science content Master’s degrees, and even scientific research experiences (Banet & Ayuso, 2003; Bishop & Anderson, 1990; Crawford, et al., 2005; Demastes, Settlage, & Good, 1995). Or, if

conceptual gains are measured, these gains can be lost as demonstrated by delayed post-tests (Banet & Ayuso, 2003). These findings are not too surprising given the reality that evolutionary theory involves an interplay of many concepts, and is supported by multiple lines of corroborating evidence—requiring well-trained teachers, careful planning and delivery on the part of the teacher, higher level thinking on part of the learner, and adequate amounts of instructional time (Demastes, Settlage, & Good, 1995; Demastes, Good, & Peebles, 1996; Smith, 2010). These variables often do not coalesce in the classroom. Even if these variables are met, accommodation of the scientific conception still may not occur due to phenomena occurring outside the boundaries of the classroom.

Second, students bring alternative conceptions into the learning environment, which sometimes enhance, but more often inhibit or complicate the learning process. At first glance, these alternative conceptions appear to be simple matters of cognition that can change through rational-based pedagogical methods. However, research has shown that these alternative conceptions are far more deep-seeded in the social, cultural, affective, epistemological, metaphysical, and dispositional landscapes of the learner (Anderson, 2007; Cobern, 1994, Sinatra, Brem, & Evans, 2008). They can be rational in their own way, rooted in learners' experiences and worldviews, and highly resistant to change. For instance, students display teleological notions of evolution as a process that gives rise to more perfect forms, a notion most likely influenced by modern societal ideas of efficiency, achievement, and progress (Nadelson, 2009). Another area of complication is a matter of semantics. The colloquial use of certain terminology is quite different from the scientific use of the term (e.g., theory, fitness, competition, adaptation). In a sense, students must learn a new language different from the one they have been immersed in day-in and day-out. They must learn the language of science in

order to properly understand evolutionary theory (Moore, et al. 2002; Sinatra, et al. 2008). These are two of many alternative conceptions that must be explicitly addressed toward conceptual change (see the next section for a more complete review of alternative conceptions).

Third, perceived controversy between religion and evolutionary theory may be the single biggest barrier to the teaching and learning of the theory. The media, teachers, family, church members, friends, etc., all influence the learner. So, a single well taught unit on evolution might be a drop in the bucket compared to a lifetime of influence from these other voices. The media can be misleading (Alters & Nelson, 2002). The media portrays evolution as *just* a theory and as a controversial topic among scientists—a truth, but with one important nuance—they are arguing about exactly *how* evolution happened, not *if* it happened. Teachers of science can also stray from their objective course. Some hope that their students embrace creationism—even support giving creationism equal time beside evolutionary theory—in *spite* of comprehensive staff development on the science content and nature of science (Nehm & Schonfeld, 2007). Those with the most influence (family, friends, clergyman) may proclaim evolution to be in stark contrast to their notions of Truth—a world divinely conceived, governed by constancy, simplistic, with man taking a special place in nature. Accepting evolutionary theory might initiate that single crack in one's reality and self identity, a possibility too scary for some to fathom, and learning may shut off completely in this case (Aikenhead, 1998).

Last, could our ability to accommodate evolutionary theory be a consequence of our genetically set personalities, even selective pressures? Sinatra, Southerland, McConaughy, and Demastes (2003) found that individuals apt to open-minding thinking (willing to question their own belief sets) and inclined to see the world as multifaceted rather than black and white showed greater gains in understanding and acceptance of evolutionary theory. Seeing the world in black

and white may not help one ace their biology exam on evolution, however, it may help them win the real evolutionary game. Sinatra et al. (2008) hypothesized that there could be selection for individuals who can make quick decisions in a dire situation, as there is no time to ponder all of the options when faced with the predatory grin of the Sabertooth. So, an understanding and acceptance of evolution could be an example of variation existing in our own human population. And as Meadows posited (2007), this variation could be “a multiallelic trait” to use a genetic analogy. Individuals may be codified along a continuum of belief between young earth creationist and atheist. Whereas, a dichotomous categorization of acceptance versus non-acceptance is over simplistic.

In sum and based on the literature, the learner is central in a web of competing conceptual forces; several have been explicated here. This gives rise to new questions. What are the goals of evolution instruction? Should we include evolution as part of scientific literacy given all the social complexities and controversy around the topic, the meager conceptual gains achieved when teaching the topic, and possible negative ramifications of exposing students to ideas which may shake their worldviews? The next section makes the case for why we *should* teach evolution. Future sections will explore various arguments regarding how to teach the topic most effectively.

Why teach evolution?

If evolution is such a polarizing topic and difficult to teach and learn, then why teach it at all? What’s the point? Efforts so far as educators have been marginally fruitful and may even shut down learning altogether. And, from interactions with the media that evolution is a hot topic

that produces inflammatory results. So why not avoid the topic and focus on the myriad other scientific concepts like food chains and food webs? The experts and even students have some answers.

To many scientists, evolution is as central a concept to biology as supply and demand is to economics. It is a necessary framework—a unifying theme—for understanding biology.

Dobzhansky (1973) explained that

[s]een in the light of evolution, biology is, perhaps, intellectually the most satisfying and inspiring science. Without that light it becomes a pile of sundry facts—some of them interesting or curious but making no meaningful picture as a whole” (p. 129).

Evolutionary theory has explanatory power, meaning the ability to answer higher level questions beginning with the words how or why: why do chordates progress through similar stages of embryonic development and share homologous structures, why do living things share “biologic universals” such as the coding molecules DNA and RNA, and how did the diversity of life arise? Answering such questions is an attempt to provide deeper understandings and assimilate observable facts into overarching themes which scientists call theories. Evolutionary theory as an explanation of the scope of scientific observation succeeds in doing just this. Scott (2004) explained that “[t]heory formation—explanation—is the goal of science, and nothing we do is more important” (p. 241). Evolution should therefore be a major emphasis in science education so that we may move beyond teaching science as trivia and testing for recall of minutia. We must challenge students to conceptualize the big ideas; we must help students move beyond “seeing the trees” to “seeing the forest.”

Notions of ethics, literacy, democracy, practicality, culture and even morality further support the teaching and learning of evolution. First, science teachers have an ethical

responsibility to accurately represent the discipline in which they teach. They are the conduits of knowledge between scientists and learners of science, and must objectively and honestly play their professional role. Parallel logic would require that social studies teachers give fair time to topics such as communism and world religions, in spite of their own personal leanings. Leaving out perceived topics of conflict such as evolution in classroom conversations would approximate “education malpractice” (Smith, 2010b, p. 544). Literacy in evolutionary theory is also quintessential for daily and democratic practice. Topics such as bioethics, extinction, climate change, human origins, cloning, conservation, bioengineered foods, antibiotic resistant bacteria, etc. pervade conversations and influence decisions on the local, international, and global stage. If citizens cannot engage in such conversations, then they will be ill-prepared to make prudent decisions that affect wide-sweeping policy from the voting booth.

Last, Catley (2006) called on our affective sensibilities to glean the prophetic, fatalistic message inherent in evolutionary thought. “The sense of humility gained through an appreciation of the kinship of all life is a vitally important component in nurturing a stewardship ethic for a planet moving ever deeper toward ecological collapse...[which could] have momentous reverberations for future generations” (p. 781). One study queried students about their opinions. Woods and Scharmann (2001) asked whether they thought evolution should be taught in schools. Eighty percent of the 49 participants agreed that the topic should be covered; they considered the topic to be important in the realm of science, important for the future, and important theory regarding how we humans got here.

How should we teach evolution?

Addressing alternative conceptions.

Cognitive psychologists and conceptual change theorists have agreed. Teaching and learning begins by establishing what the learner already knows (Ausubel, 1968, Piaget, 1978, Vygotsky, 1978, Posner, Strike, Hewson, & Gertzog, 1982). Learning cannot proceed in a mental vacuum because new knowledge must have a hook on which to hang, somewhere to stick, a place to land. Otherwise, it is ephemeral, temporarily entertained by the learner but making no indelible mark on the learners existing conceptual framework. An analogy can be drawn from a carpenter who cannot build “castles in the sky”. With the task of adding to and remodeling an old house, he/she must first establish the topography of the landscape and the dimensions of the existing structure. Likewise, educators are challenged to understand our students’ mental blueprints; we must have some sort of tangible foothold from which to start before we can help students tweak, add to, modify, adjust, or remodel their prior knowledge.

Consistent with learning theory, the academy has conducted much research on identifying student prior knowledge regarding evolution. Similar terms to prior knowledge such as naïve conceptions, misconceptions, and alternative conceptions are also used in the literature, but they all refer to those conceptions that stray from the accepted scientific conceptions. Prior conceptions identified in the literature were codified into four tables. Table 2.1 enumerates content-based prior conceptions (e.g., teleological and Lamarckian conceptions). Table 2.2 lists prior conceptions regarding the nature of science. These prior conceptions are relevant here because understandings of the nature of science and evolution illuminate one another. Table 2.3 lists prior conceptions dealing with human evolution. This information is listed separately because human evolution as a pedagogical theme has been rarely employed yet may render

significant learning gains. Last, Table 2.4 lists prior conceptions dealing with belief. An awareness of such conceptions has become more important in light of recent research suggesting that the affective domain influences one's understanding, belief, and acceptance of evolutionary content.

Table 2.1 <i>Alternative Conceptions of Evolutionary Theory</i>	
Alternative Conceptions	References
Individual characteristics change out of need or use and disuse	Alters & Nelson, 2002; Bishop & Anderson, 1990; Brumby, 1984; Crawford, et al., 2005; Demastes, Good, & Peebles, 1995; Jensen & Finely, 1995; Tamire & Zohar, 1991
Single individuals “adapt”, changing genotypically or phenotypically	Bishop & Anderson, 1990; Jenson & Finely, 1995; Crawford, et al., 2005
<i>Fitness</i> used in the theory of natural selection refers to anthropomorphic notions of preferred characteristics (e.g. strength, endurance, and prowess).	Bishop & Anderson, 1990
The environment causes evolution	Alters & Nelson, 2002; Bishop & Anderson, 1990;
Evolution leads to progress	Dagher & Boujaoude, 1997; Naegle, 2009; Tamir & Zohar, 1991
All individuals in a species adapt or change	Alters and Nelson, 2002; Bishop and Anderson, 1990
All individuals in a species are the same; there is no variation	Jensen & Finely, 1995; Moore et al. 2002
Species evolve to their environment more often than they go extinct	Jensen & Finely, 1995
Evolution is waged by random events	Daugher & Boujaoude, 1997
All mutations are harmful	Cho, Kahle, & Nordland, 1985; Nehm & Schonfeld, 2007
Mutations occur in response to environmental changes	Jensen & Finley, 1995
Mutations consist of any change in an individual	Albaladejo & Lucas, 1988
Evolution occurs over shorter periods of time and not millions of years	Tamir & Zohar, 1991
Evolution is based on little evidence; there is no proof.	Daugher & Boujaoude, 1997; Sinatra, et al., 2003
Evolution is weak because it is just a theory	Daugher & Boujaoude, 2005; Nehm & Schonfeld, 2007
Evolution cannot be observed so it cannot be studied by science	Nehm & Schonfeld, 2007
Evolution cannot be disproved by an observation	Nehm & Schonfeld, 2007
Evolution cannot be “proven”	Nehm & Schonfeld, 2007
The fossil record is relatively incomplete	Nehm & Schonfeld, 2007
Microevolution is more scientifically accepted then macroevolution	Daugher & Boujaoude, 2005

Table 2.2 <i>Alternative Conceptions of the Nature of Science</i>	
Alternative Conceptions	References
Scientific theories are educated guesses, based on conjecture.	Alters & Nelson, 2002; Dagher & BouJaoude, 2005
Theories become laws or facts when they become more supported by evidence.	Dagher & BouJaoude, 2005; Nehm & Schonfeld, 2007
The knowledge generated by science and creationism is the same type of knowledge.	Crawford, et al., 2005
Theories cannot be proven (so evolution cannot be proven).	Dagher & Boujaoude, 2005
Evidence is trustworthy if it is obtained through direct observation only (so the evidence for evolution is not trustworthy)	Dagher & Boujaoude, 2005
All scientific inquiries must be approached through a strict scientific method (evolution must not be as valid since its study is not approached through this method).	Dagher & Boujaoude, 2005; Crawford, 2005
Science knowledge does not change.	Anderson, 2007; Sinatra, et al., 2003
Scientific conclusions are Truth.	McComas, 1988
Science provides absolute proof.	Chiapetta & Koballa, 2004; McComas, 1998
Science can answer all questions.	McComas, 1988

Table 2.3 <i>Alternative Conceptions about Human Evolution</i>	
Alternative Conception	Reference
Humans evolved from monkeys or extant apes.	Daughter & Boujaoude, 1997; Woods & Scharmann, 2001
Evolution has taken place in order to produce humans, the supreme race.	Daughter & Boujaoude, 1997; Jensen & Finley, 1996
Humans developed their characteristics for teleological reasons (e.g., Humans did not need a tail so it disappeared).	Tamir & Zohar, 1991
There are no fossil species that may link humans and apes.	Nehm & Schonfeld, 2007
Humans and dinosaurs existed at the same time.	Nehm & Schonfeld, 2007
Humans evolved in the last 10,000 years.	Newport, 2004

Table 2.4 <i>Alternative Conceptions about Belief</i>	
Misconceptions	References
One has to either believe or not believe in evolution.	Anderson, 2007
If one accepts evolution, then they are atheists.	Anderson, 2007; Jackson et al., 1995
If one accepts evolution, then they are immoral.	Jackson et al., 1995
Evolution is a black or white, yes or no issue.	Anderson, 2007

As demonstrated in the Tables 2.1-2.4, student prior conceptions regarding evolution are well documented and diverse. Researchers have agreed that explicitly addressing these prior

conceptions is critical for learning. However, approaches differ. The next sections will focus on the various conceptual change models and pedagogical approaches that have been used to address student prior conceptions toward more scientific understandings of biological evolution.

Conceptual change models in evolution education

One the first conceptual change models was proposed by Posner, Strike, Hewson, and Gertzog (1982). Posner, et al. viewed learning as a cognitive process, assuming that a learner would replace, wholesale, a misconception as soon as they came to know the superior, more rational scientific one. Such conceptual change could occur by meeting the following four criteria: 1). Introduce learners to anomalies so that they become *dissatisfied* with their alternative conception, 2). Provide learners with opportunities to grapple with new conceptions so that they become *intelligible* or simply make sense, 3). Help learners see the new conception as *plausible* or a possible candidate of truth, and 4). Help learners see the new conception as *fruitful* or giving rise to new lines of inquiry. Multiple research attempts in evolution education employed this learning model. All measured post-intervention cognitive gains. However, these cognitive gains were less than optimal, leaving much to be desired. Unexpected findings also surfaced as enumerated below:

- Instructional approaches (both direct and inquiry-based) produced nominal cognitive gains. At best, 50 percent of participants expressed correct understandings of Darwinian evolution as measured by post-tests (Bishop and Anderson, 1990; Jensen and Finley, 1995; Demastes, Settlage, and Good, 1995).

- Various patterns of conceptual change occurred unlike the wholesale changes predicted by Posner, et al., 1982. Students held two competing conceptions at once (e.g., mutations are random and individuals change out of need), and developed understanding through a cascade of incremental steps (Demastes, Settlage, & Good, 1996).
- Learners displayed correct understandings of evolutionary mechanisms on the post-test, but then digressed to Lamarckian explanations on the delayed post-test (Banet & Ayuso, 2003)
- Students understood the scientific conception but did not believe and/or accept it. Inversely, students understood the scientific conception but did not believe and/or accept it (Demastes, Good, & Peebles, 1995).

Early applications of the CCM in evolution education produced common conclusions: misconceptions are deep-seeded and resistant to change, conceptual change is not a simple matter of cognition, evolution is a difficult topic to teach, and more research is needed to flesh out the complexities of evolution as a teaching and learning topic

Improvements to conceptual change theory soon developed. Strike and Posner (1992) critiqued and modified their original model. They recognized that misconceptions are not as well conceived prior to learning. They may not exist at all, exist in a vague, intuitive form, or develop on the spot during instruction. They also realized that cognition is not the only factor that drives conceptual change. Therefore, they broadened their definition of one's conceptual ecology to include aspects of the affective domain—motivations, goals, beliefs, and social and institutional contexts. The Cognitive Reconstruction of Knowledge Model (Figure 2.1) developed by Dole and Sinatra (1998) illustrated these new developments in theory. Their model showed that for

strong conceptual change to occur, many cognitive and affective criteria must be met: (a) The pedagogical message must be *comprehensible, coherent, plausible, and rhetorically compelling* as in the original CCM, (b) A learner's misconception needs to be weak in terms of strength, coherence, and commitment, (c) A learner needs to be motivated as a product of dissatisfaction with their prior conception, relevance in the learning topic, or positive social influence from peers, and (d) The learner needs to put forth high levels of intellectual engagement. An important implication to this model is that conceptual change is difficult given all of the components that must be met before it can occur.

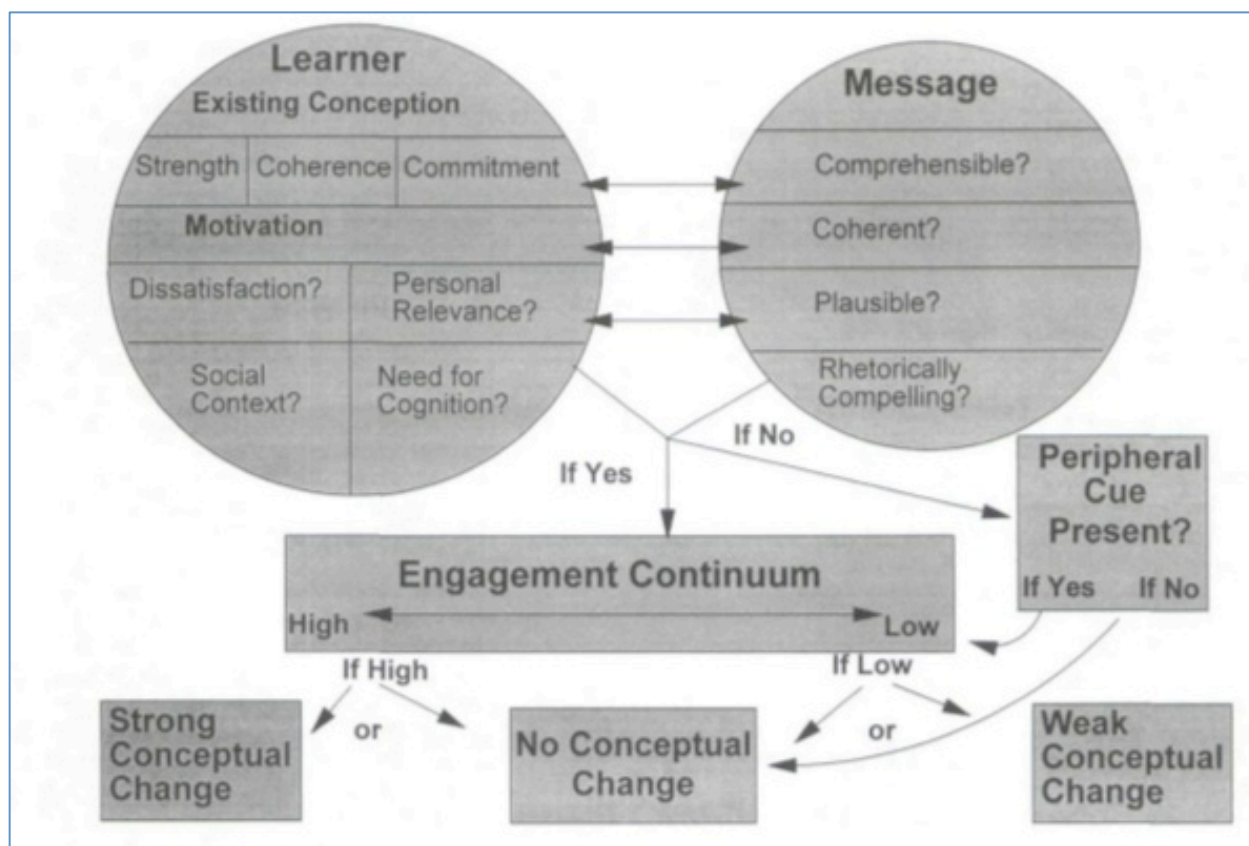


Figure 2.1. Dole and Sinatra's (1998) Cognitive Reconstruction of Knowledge Model. Strong conceptual change relies on a strong cognitive message and the conceptual ecology, motivation, and engagement of the learner.

The theory around the CRKM has been tested in evolution education research. Sinatra, Brem and Evans (2008) supported the model, especially when dealing with a personal, complex, and controversial topic like evolution. Sinatra et al. found that high levels of conceptual change occurred when teaching photosynthesis, but not when teaching evolution. This makes sense when considering the CRKM model. First, photosynthesis is not as complex as evolutionary theory; high levels of cognition can be met fairly easily with photosynthesis, whereas an understanding of evolution takes more cognitive work. Second, students may come to photosynthesis with some misconceptions, but learners are likely to be weakly attached to them, and open to the scientific conception as it is presented. The concept of evolution runs in stark contrast. Students hold well-formed religious convictions that they are highly committed to, and that are reinforced by everyday cultural experiences. Evolutionary theory is less likely to penetrate such conceptual frameworks steeped in religious worldviews. Third, motivating students to learn about photosynthesis is reasonably achievable-students can see that it is relevant to our own existence, find it cognitively challenging and engage amenably with peers about the topic. Motivation for learning evolutionary theory is not so easily attainable because learners may never become dissatisfied with their religious worldview to even consider an alternative one, may *not* see evolutionary theory as relevant to their daily lives, or may be influenced by peers to be skeptical and disengaged. The findings of Sinatra, et al. were significant, suggesting that the affective domain in learning is more critical in conceptual change, and that conceptual change is more difficult when dealing with a personal, controversial topic like evolution.

In sum, new developments in conceptual change theory make explicit the notion that accepting evolutionary theory often requires radical shifts in one's worldview, as it requires one to break with the everyday world, with one's notion of *Truth* (Cobern, 1994). So, achieving

conceptual change in evolution is unlikely, which calls for a reconceptualization of the goals for evolution education. A new consensus regarding such goals has emerged. The main goal of evolution education should help students gain *understandings* of why evolutionary theory is the most well supported *scientific* explanation for the diversity of life on planet. However, a goal should not be to require students to accept or believe in the theory (Cobern, 1994; Smith and Siegel, 2004). Other researchers also suggest that pedagogy help students “find a place to stand” (Scharmann, 1990, p. 98) between two dichotomous extremes of science and religion before and during learning experiences designed for understanding.

Pedagogical approaches to the teaching and learning of evolution.

Table 2.5 lists the various pedagogical approaches that have been applied in evolution education. Most are not applied in isolation, but are applied in various combinations.

Table 2.5 <i>Pedagogical Approaches to the Teaching and Learning of Evolution</i>	
Pedagogical Approach	Reference
Address student prior conceptions	Banet & Ayuso, 2003; Bishop & Anderson, 1990; Demastes, Settlage, & Good, 1995; Jensen & Finley, 1995; Nelson, 2008
Students engage in active learning, the opposite of behaviorism.	Alters, & Nelson, 2002; Banet & Ayuso, 2003; Nelson, 2008
Students engage in inquiry-based, contextualized tasks (learning couched in the methods, norms, and language of science) to learn science process and evolutionary theory; learning is discipline specific.	Crawford, et al., 2005; Passmore & Stewart, 2002; Sandoval & Reiser, 2004
Students learn by engaging in argumentation	Anderson & Wallin, 2006; Asterhan & Schwartz, 2007; Nelson, 2008; Passmore & Stewart, 2002; Sandoval & Reiser, 2004; Sinatra, et al., 2008
Students use technology to learn evolutionary theory.	Crawford, et al., 2005; Sandoval & Reiser, 2004
Students reflect on changes in scientific conceptions.	Alters & Nelson, 2002; Demastes, Settlage, & Good, 1996; Sandoval & Reiser, 2004
Students engage I reflection to re-examine their own worldviews during and after instruction.	Anderson, 2007; Alters & Nelson, 2002
Students compare the scientific versus colloquial use of terminology (e.g., fitness, competition, adaptation, theory).	Daugher & Boujaoude, 1997
Students engage I discussion with other students to grapple with the content. The discussions are structured and scaffolded by the teacher.	Nelson, 2008; Passmore & Stewart, 2002
Students engage in sense-making by constructing concept maps.	Alters & Nelson, 2002

Students study the historical development of Darwinian theory.	Alters & Nelson, 2002; Jensen & Finley, 1995
Evolution is taught as a unifying theme throughout a science course.	Alles, 2001; Demastes, Good, & Peebles, 1995; Demastes, Settlage, & Good, 1996
Focus on big ideas or essential questions rather than minutia	Alters & Nelson, 2002
Teach the NOS in tandem with teaching evolutionary theory	Alles, 2001; Alters & Nelson, 2002; Passmore & Stewart, 2002
Compare the NOS to other disciplines of thought	Alters, & Nelson, 2002; Anderson, 2007; Anderson & Wallin, 2006;
Provide tools to help students deal with the perceived conflict between science and religion	Alters & Nelson, 2002; Nelson, 2008; Scharmann, 1990; Scharmann, 1993; Scott, 2004; Woods & Scharmann, 2001
Teach macroevolution	Catley, 2006
Use human evolution as a vehicle for learning evolutionary theory	Nelson, 2008
Discuss evolution and creationism issues (e.g., news reports, gallop poll results, court decisions, Eugenie Scott's (2004) belief continuum)	Jackson, 2007
Openly address issues of religion as they arise because these concepts are a part of students' prior conceptions; to do so would be in line with constructivist learning theory	Alters & Nelson, 2002; Anderson, 2007
Explicitly address the affective domain (motivations, goals, beliefs, etc.) during learning.	Anderson & Wallin, 2006; Daugher & Boujaoude, 1997; Scharmann, 1990; Scharmann, 1993

Many of these pedagogical approaches have been proposed in theory (e.g., Anderson & Wallin, 2006; Passmore & Stewart, 2002). Others lack sound methodological approaches; they have small samples sizes (e.g., Sandoval & Morrison, 2003), lack pedagogical and/or curricular detail (e.g., Alles & Stevenson, 2003), and lack of reliability and validity evidence (e.g., Stewart & Rudolf, 2001). Few pedagogical methods for teaching evolution have been empirically founded; a few are listed below:

- Banet and Ayuso (2003) measured significant student gains in understanding evolutionary concepts when employing constructivism (active learning) over an extended amount of instructional time (six weeks). Seventy percent of students (n=82) expressed normative scientific views post-intervention compared to 44% pre-intervention.
- Crawford, Zembal-Saul, and Friedrichsen (2005) employed inquiry, situated learning, technology, and metacognition over twelve hours of instruction. Learners used real

scientific data (Galapagos finch data from Peter and Rosemary Grant) to make sense of microevolutionary processes. Fourteen of eighteen prospective teachers demonstrated conceptual change toward normative conceptions.

- Scharmann (1990) allowed students (n=30) to discuss their opinions about evolutionary theory and creation. Students showed significant increases in nature of science understandings and acceptance of evolutionary theory.
- Smith and Scharmann (2008) used a nature of science and social construction of knowledge model over 12 hours of instruction. They also used the learning cycle (5 E's) and created a respectful environment of learning. All fifteen students recognized evolution as “most scientific” at the end of the intervention, and three of the case studies accepted evolution after instruction albeit with varying degrees of understanding and emotional influence.

The cumulative results of these pedagogical studies support the following pedagogical approaches: long-term constructivist activity, inquiry, situated learning, metacognition, nature of science learning experiences, social construction of knowledge, scaffolds for supporting learning, and eliciting student opinions. More research may need to be conducted to discern the most effective combination of these pedagogical approaches and how to translate these approaches into daily learning experiences.

Teaching and learning about human evolution

A case for teaching human evolution has been made in the literature. Few studies empirically support such pedagogy, but this approach may have the biggest potential for creating rich learning experiences.

Nickels (1987) drew on constructivist notions of how one learns. Constructivist theory presumes that motivating students to learn starts by activating what one already knows and relating learning to this pre-existing conceptual ecology. Thus, Nickels (1987) suggested that students should learn about evolution by “studying themselves,” looking to their own evolutionary past. Doing so would personalize learning and make learning more concrete, understandable, and accessible because “it is as though they are gazing into a mirror instead of having to peer down a microscope” (Nickels, 1987, p.144). Alles and Stevenson (2003) made their case from an anthropomorphic, epistemological perspective. They explained that “self knowledge is the most valuable knowledge we can possess,...[and] what modern science can tell us about who and what we are is the most valuable knowledge we can teach our students” (p. 334). In sum, teaching evolution by learning about how our own species evolved would personalize the learning situation and ultimately motivate students unlike other approaches that use non-human examples. Dole and Sinatra (1998) concurred, arguing that human evolution is a personally relevant topic that would increase students’ motivation to learn.

Teaching human evolution addresses several alternative conceptions that serve as barriers to understanding and accepting evolutionary theory in general. One student alternative conception documented by Daugher and Boujaoude (1997) and Woods and Scharmann (2001) included the view that “humans evolved from monkeys”. No scientist has claimed this as such, and one of my students summarized it well, “we actually learned how it's like humans evolved from humans and there's the missing link between gorilla's and apes and humans. But so far, it just looks like we evolved from ourselves” (Beall, 2007). *Homo heidelbergensis*, *Homo erectus*, and *Homo habilis* are our (*Homo sapiens*) most recent ancestors, sharing the first name *Homo* to signify that we are all in the same genus of “man”.

Students also think that the fossil record is relatively incomplete (Nehm & Schonfeld, 2007), that the evidence for human evolution is shaky. However, what we know about our human past centers on an extensive amount of fossil evidence (Freeman & Herron, 2007; Larsen, Matter, & Gebo, 1998; Lewin & Foley, 2004; Stringer & Andrews, 2005); approximately twenty extinct hominin species have been identified by fossil remains, some in the direct evolutionary line of our species (e.g., *Homo erectus*), and others that have branched, gone extinct, and represent evolutionary dead ends (e.g., *Homo neanderthalensis*). The assimilation of all the fossil remains within one evolutionary tree, however, presents an impressive array of hominin diversity. One of my students said that “it was interesting to see how many compared to humans were actually alive...and there was only one of us. But it’s cool to see your ancestors” (Beall, 2007). This “sound, reliable, well-documented evidence that humans among all species have evolved” makes a convincing case for evolutionary theory in general (Nickels, 1987).

Teaching human evolution is also a great way to teach macroevolution, an aspect of evolutionary theory that is often ignored during instruction, (Catley, 2006), but may have the greatest potential in cultivating understanding (Nadelson & Southerland, 2010b). Macroevolution embodies concepts dealing with deep time, fossils, extinction, speciation, and evolutionary trees (Nadelson & Southerland, 2010a). Most evolution curricula focus on microevolutionary processes such as natural selection and mutation (Catley, 2006). For example, students study the selection of dark-colored peppered moths during the industrial revolution. These examples facilitate student understandings of evolution within a species, a notion more commonly accepted (Daugher & Boujoude, 2005), but require students to make leaping extrapolations when conceptualizing evolution as the divergence of species. Students must learn about macroevolution in order to gain a holistic picture of evolutionary theory (Anderson &

Wallin, 2006; Catley, 2006); human evolution provides an explicit example of new species arising from ancestral ones over millions of years. My students showed an understanding of macroevolution because “they [hominins] evolved over time” and in terms of years, evolution takes, “maybe longer than millions, maybe tens of millions, hundreds of millions maybe. Either way it's a really long time. A lot longer than anyone's been around” (Beall, 2007).

Neither my major research professor nor I have experienced negative backlash from students, parents, or administrators when teaching human evolution to over 10,000 students in one of the most Christian conservative areas of the country. Perhaps it is our delivery that creates a motivational and safe environment. This study will hopefully discern if this is so.

Last, studying human evolution, or paleoanthropology, creates a fertile ground for discussing NOS concepts (Desilva, 2004). Science is far from definitive, but an ongoing process of knowledge generation, testing, and modification. Science knowledge, hypotheses, and interpretations change in light of new evidence. Paleoanthropology exemplifies this tentative, dynamic nature of science, in which new fossil finds may bring about more questions than answers, spark contentious debates among the experts, and even overturn long-held views of our human origins. Through the study of paleoanthropology, learners can revisit their alternative conceptions of science, gaining important insights into the true nature of science.

Using hominid skulls to teach evolution

At least ten attempts to teach biological evolution and/or human evolution through the use of hominid skulls have been documented in the literature (Desilva, 2004; ENSI, 1999; Gipps, 1991, 2005; Koopman, 2001; Robertson, 2007; Thomson & Beall, 2008). Hominid refers to a taxonomic group including extant chimpanzees and gorillas, and hominins. Hominins are a taxonomic group including *Homo sapiens* and their extinct ancestors characterized by the shared

and derived characteristics of bipedalism and reduced canines (Woods & Lonergan, 2008). I analyzed all of these articles to situate my study in the academic literature.

Most of these articles were written for high school and college biology instructors. Two articles (ENSI, 1999a & 1999b; Thomson & Beall, 2008) addressed middle school teachers. All authors made positive claims about their pedagogical approaches, yet no empirically based articles were found to support the claims made, suggesting an open field for future research and my study. This section explored the pedagogical approaches used by these authors, and reported the claims these authors made about teaching and learning outcomes. The gaps in the literature were also noted.

Using hominid skulls: Ultimate goals

All authors aimed to promote student understandings of “modern scientific thinking” (ENSI, 1999a) regarding evolution. Emphasis was often placed on students understanding why scientists thought as they did regarding evolution, and the evidence behind such thinking. The larger science education community also supports presenting evolutionary theory as an “undeniable understanding of the science community” (Meadows, 2007, p.153), while letting “belief fall where it may” (Smith & Siegel, 2004, p. 579). Meaning, acceptance of evolutionary theory should not be an instructional goal. Articles published after 1991 also expanded “modern scientific thinking” to include the relationship between evolutionary theory and the nature of science, also supported in the larger science education community (e.g., Meadows, 2007). Nickels (1987) and Gipps (1991) were unique in aiming to promote acceptance of evolutionary theory—attempting to unravel student misconceptions in order to promote scientific thinking over creationism.

Using hominid skulls: Pedagogical commonalities

Three common themes permeated all of the articles reviewed: a) students practicing comparative anatomy, b) students engaged in scientific inquiry, c) and students demonstrating motivation to learn.

Nickels (1987), who first documented the use of hominid skulls during instruction, explained the benefits of the comparative anatomy method. He explained that comparative anatomy was a century old practice of evolutionary biologists to infer “patterns of evolutionary kinship between both fossils and living forms” (p. 144). Students engaged in comparative anatomy, and thus, engaged in “authentic” scientific practice supported by the NSES (1996, p. 31).

Although authors reported using different extinct hominid skull combinations and amounts, all authors reported using extant humans, gorillas, and/or chimpanzees as reference points for making claims regarding the extinct hominin unknowns. Students often began the lessons by making qualitative and quantitative observations of humans, gorillas and/or chimpanzees. Next, students took on the study of one or more extinct hominin skull(s), making claims regarding diet, posture, placement within the hominid phylogenetic tree, etc. Expertise in extant mammology is an imperative skill for paleoanthropologists (R. Bobe, personal communication, August, 12, 2012), and thus was a requisite skill for these learners of human evolution.

All of the articles reviewed mentioned students’ use of inquiry, particularly in making evidence-based claims (NSES, 1996). All pedagogical approaches challenged students to make qualitative and/or quantitative observations of 3-D hominid skull specimens or photographs. Inferences, explanations, and analyses based on these initial observations ensued:

- Was the hominin more human-like or ape-like (Nickels, 1987; Gipps, 1991, 2005)?
- What came first: large brain or upright stance (Gipps, 1991)?
- Where would this specimen fit in or change a hominid evolutionary tree (Desilva, 2004; ENSI, 1999c; Gipps, 1991; Robertson, 2007; Thomson & Beall, 2008)?
- What was the life history of this specimen (Robertson, 2007; Thomson & Beall, 2008)?
- What craniometric/evolutionary patterns existed among specimens (Desilva, 2004; ENSI, 1999b & 1999c; Robertson, 2007; Thomson & Beall, 2008)?

Therefore, students were encouraged to use evidence to support claims (i.e., inferences, explanations, hypotheses, phylogenies, etc.)—an essential feature of science (NSES, 1996). Four authors (Desilva, 2004; ENSI, 1999b & 1999c; Thomson & Beall, 2008) also encouraged “enquiry” (Schwab, 1962, p. 65)—inquiring into the process of inquiry to better understand how and why scientific knowledge is created (i.e., NOS).

The third common feature was the ability of the 3-D extinct hominid skulls/photographs to incite “enormous interest” (Gipps, 1991, p. 283). Nickels (1987) explained students might be so excited because of anthropomorphic reasons. He explained that “Beginning with humans is virtually guaranteed to interest even the most non unenthusiastic of your students in the study of evolution...because they are studying themselves”(p. 143). Other authors mentioned the tactile nature of the skulls, which Gipps (1991) dubbed “concrete appeal” (p. 284). Last, the in-depth and meaningful pedagogical strategies may have fostered intrinsic motivation (NRC, 2003). The use of driving questions (e.g., Gipps, 1991), performance assessments (Thomson & Beall, 2008) and minds-on activity such as engaging in inquiry, argumentation, and critiquing claims (e.g., Desilva, 2004) served as examples of intrinsically motivating learning experiences that I identified through this section of the literature review.

Using hominid skulls: Pedagogical differences

Authors offered distinct approaches regarding the use of hominid skulls during instruction. Nickels (1987) was alone in suggesting that using 3-D skulls was “extremely simple” because learning was based on direct observations of physical skull characters and comparative anatomy; students needed no prior knowledge or training (p. 144). Nickel’s (1987) claims aligned with constructivist and conceptual change theory, which requires learning to encompass features of relevance (i.e., the real world of evolutionary biology) and an appropriate level of challenge. And perhaps, this is why all of the authors reporting positive experiences regarding the use of hominid skull replicas, utilized comparative anatomy as a central pedagogical feature.

Authors varied in the number of 3-D hominid skulls or photographs used. One author (Robertson, 2007) utilized only eight hominid skulls, while another, Desilva (2004), utilized up to 41 photographs. The number of skulls/photographs related to lesson design, and was not necessarily representative of pedagogical richness. Robertson (2007), for example, required students to choose four out of eight available hominids; student exposure to a representative sample of hominid variation was emphasized over quantity. Desilva’s lesson, however, challenged students to compare and contrast three phylogenies constructed by three different expert paleoanthropologists; examining a complete hominid tree worth of skull photographs transpired to complete the requirements of this lesson experience. Thomson and Beall (2008), also required a large library of skulls to complete their lesson experiences. They used thirteen extant mammalian skulls to scaffold student inquiries with ten extinct hominin skulls.

Authors also offered their own unique pedagogical twists. Gipps (1991) employed the use of two driving questions to drive the comparative anatomy process: Which of these skulls is “human”?, and What came first: large brain or upright stance?—similar to a project-based

pedagogical format (Blumenfeld, et al., 1991). Nickels (ENSI, 1999b) scaffolded student inquiries with a detailed hominid data chart. Then, students graphed their quantitative data to identify evolutionary trends, in order to take on higher order questions also posed by the paleoanthropological community.

Desilva (2004) was the first of these authors to share the notion that the discipline of paleoanthropology holds the greatest potential for student discoveries of NOS concepts (e.g., exploring the differences between belief, hypothesis, and theories). Desilva (2004) was also the first to challenge students to analyze the differences among phylogenies developed by the experts, before developing their own phylogenies and considering the evolutionary placement of a new fossil discovery. Desilva (2004) and Flammer (ENSI, 1999c), explicitly taught students how to pictorially represent phylogenetic relationships among fossils (through dotted lines, straight lines, no lines, or circles).

Thomson & Beall (2008) were unique in their pedagogical delivery as well. They scaffolded future inquiries of hominin evolution with a) explorations of a crime scene to conceptualize retrodictive inquiry (Ben-Ari, 2005) and, b) observations of extant mammalian skulls to practice comparative anatomy. Students also simulated a fossil dig and identified their fossil discoveries using a dichotomous key. Students explicitly grappled with the difference between observation and inference in conducting retrodictive inquiry, and conducted independent research to share at mock, peer-reviewed science symposia. Principles of backwards design (Wiggins & McTighe, 1998) and project-based learning (Blumenfeld, et al., 1991) were employed. Last, Robertson (2007) was the only author who reported the student use of digital cameras to generate digital craniometric data for analysis.

Using hominid skulls: Pedagogical progressions

Several pedagogical progressions were evident from 1987 to 2008, reflecting other developments in teaching and learning theory, science education research, and paleoanthropology discovery.

One progression included the degree in which students engaged in inquiry. The use of inquiry became more intensive and student-centered with time, student-centered referring to the degree of active learning, peer collaboration, student choice, and student responsibility for learning. For instance, earlier pedagogical approaches (Nickels, 1987; Gipps, 1991) challenged students to complete a prescribed checklist to collect mostly qualitative data to address one or two teacher developed driving questions. However, learning experiences in later articles required more intellectual engagement (Banilower, et al., 2008) from students. Students analyzed data for trends (e.g., ENSI, 1999b), developed hypothetical phylogenies (e.g., Desilva, 2004), recreated the life histories of hominins (e.g., Thomson & Beall, 2008), and conducted student-generated research (e.g., Robertson, 2007). A greater array of inquiry learning over time may have reflected its increased emphasis through national science education standards (AAAS, 1993; NRC, 1996). Increased inquiry in the classroom may have also been a reflection of increased inquiries in the paleoanthropology community, made possible by an array of new hominin fossil discoveries (Freeman & Herron, 2008; Stringer & Andrews, 2005).

A second pedagogical progression dealt with conceptual change theory. Earlier skull pedagogical approaches modeled traditional, cold conceptual change theory (Posner, Strike, Hewson, & Gertzog, 1982; Pintrich, Marx, Boyle, 1993)—which challenged student misconceptions in attempt to supplant this conception, wholesale, with normative conception—

toward understanding and acceptance. For instance, a main objective for Nickels (1987) and Gipps (1991) addressed the alternative conception that humans arrived “apart from the rest of ‘creation’” (Gipps, 1991, pg. 287). They delivered clear, thorough, and rich cognitive instruction, guiding students in the exploration of extinct hominins. Through this instructional approach, Nickels (1987) and Gipps (1991) both concluded, “It is virtually impossible for any student to fail to see the continuity and gradation of form evident in these fossil specimens that is entirely consistent with the conclusion that there has in fact been descent with modification” (Nickels, 1987, p. 148). However, research using traditional conceptual change theory (e.g. Bishop and Anderson, 1990; Jensen and Finley, 1995; Demastes, Settlage, and Good, 1995) to teach evolutionary concepts, has suggested that students make minimal cognitive progress, and/or maintain or soon thereafter revert back to their original conceptions in spite of sound instructional intervention.

Later skull pedagogical approaches may have been influenced by developments in conceptual change theory (Strike & Posner, 1992; Dole & Sinatra, 1998), which encompassed the affective domain of learning (i.e., motivations, goals, beliefs, and social and institutional contexts) and a broader understanding of misconception. Theorists recognized that learners bring a complex set of prior knowledge to learning situations beyond simple misconceptions. Therefore, approaches to teaching and learning needed to recognize the broader components of a learners’ conceptual ecology (Strike & Posner, 1992) or their worldview (Cobern, 1994). Theorists also recognized that conceptual change included more than supplanting misconceptions with more logical, scientific ones. The process was messier. The nature of misconceptions varied—misconceptions might be ill-conceived to begin with, mesh with normative conception,

morph through phases of alteration, tie into belief and worldviews systems, etc. Likewise, later skull pedagogical approaches mirrored these developments in conceptual change theory.

In general, teaching and learning approaches became more student-centered (Dewey, 1938; Piaget, 1978; Vygotsky, 1978). Depth of learning, discovery learning, active learning, cooperative learning, scientific process, “enquiry” (Schwab, 1992, p. 65), critical thinking, and student choice gained emphasis. Students had more time to grapple with the 3-D hominin skulls and/or photographs in the spirit of depth of learning and discovery. The more dogmatic approach of conventional conceptual change theory was abandoned. Students took over the reigns of learning, and they were encouraged to base claims on evidence rather than come up with a predetermined “right answer”. Cognitive process became paramount over cognitive product. Students were also challenged to engage in more critical thinking with data, identifying trends, developing and testing hypotheses, critiquing claims, etc., indicative of divergent thinking, sensitive to the pluralistic, intricate, and mosaic nature of student conceptual ecology. Through the inquiry process, students grappled with the NOS. Students often had opportunities to make their own choices as well, regarding how to collect data, which data analyze, or which driving questions to pursue.

A third pedagogical progression included the integration of separate (versus fused) NOS instruction. Nickels (ENSI, 1999b), Flammer (ENSI, 1999c), and Thomson and Beall (2008) proposed the use of a pre NOS scaffolding unit before student inquiries into hominin evolution. The purpose of a free standing NOS unit, challenged students to explore the epistemology of science, limited to the exploration of the natural world. Explicitly teaching NOS in its own separate unit, served as a more sensitive approach to dealing with perceived conflict in the classroom (Meadows, 2007). Students were given tools to negotiate tensions before learning

about human evolution, by seeing that science is a separate, not superior, way of understanding the world. Teaching the NOS in separate/distinct units has shown to be effective in science education research. For instance, an explicit and reflexive unit on the NOS increased students' comfort level when thinking about evolution, increased students' acceptance of evolution as a legitimate scientific theory (Smith & Scharmann, 2008).

Desilva (2004) and Thomson and Beall (2008) more explicitly fused NOS instruction within hominin skull learning experiences, in line with hypothesis in the science education community suggesting that the fusion of NOS with content, produces synergistic learning outcomes (Alles, 2001; Alters & Nelson, 2002; Passmore & Stewart, 2002). Desilva (2004), for example, challenged students to compare and contrast three phylogenies proposed by expert paleoanthropologists. Students gained content knowledge regarding how to construct a phylogenetic tree, but more importantly learned that science is tentative; all three phylogenies were different and subject to change based on new fossil discoveries. Thomson and Beall (2008) included the paleoanthropological fraud, Piltdown man, in their library of skulls under study, to relay the notion that science can be done poorly, and that skepticism is an important aspect of the scientific process.

Using hominid skulls: Addressing perceived conflict

Authors have dealt with conflict in the classroom differently. Barbour (2000) and Herman (2008) provided useful frameworks for categorizing approaches to addressing conflict in the classroom when taking on the topic of evolution and human evolution. I referenced their frameworks in this brief discussion.

The language Nickels (1987) used in his article suggested several different approaches: advocacy (Herman, 2008), independence (Barbour, 2000), and conflict (Barbour, 2000). Nickels

used the advocacy approach because he directly countered and unraveled student ideas regarding special creation. For instance, he delivered a cognitively clear message to dispute that the *Australopithecines* represented “variation within a specially created ‘kind’” (p. 148). Nickels also utilized the approach of independence, which encouraged students to recognize the boundaries of science in studying the natural world only. Last, he utilized conflict as an approach, raising science in higher esteem than creation. He stated, “the instructor is justified in maintaining that special creation should not be considered a valid, alternative explanation for the fossil pattern under discussion” (p. 148).

Gipps (1991), took a totally different approach altogether, avoidance (Herman, 2008). Gipps (1991) mentioned no strategies such as advocacy to counter student arguments for creation, nor did he create environments in line with independence or dialogue (Barbour, 2000)--comparing creation and science in a respectful manner. However, Gipps (1991) finished his article by stating, “Perhaps the greatest value of these casts is that they enable students to gain some concept of evolution without the word itself even being mentioned, at least in the initial stages” (p. 289). Therefore, Gipps (1991) took precaution to avoid potentially abrasive conflicts and conversations in his classroom. However, Gipps’ (1991) final remarks suggested that he hoped students would see that “*Homo sapiens* is not a being apart from the rest of ‘creation’” (1991, pg. 287). So, an ulterior motive may have been for students to achieve acceptance, as well as understanding, of evolutionary ideas.

Authors who published between 1999 and 2008, were united in their approach to addressing conflict in the classroom. They utilized the independence approach by having students explicitly grapple with NOS concepts so that they could come to understand the limits and parameters of science—only interested in the natural world. As discussed in previous

paragraphs, some authors devoted time to a separate NOS unit prior to learning about human evolution (e.g., ENSI, 1999a). Others, fused NOS instruction within learning experiences of human evolution (e.g., Desilva, 2004), while one article reported doing both (Thomson & Beall, 2008). None of the articles published between 2003 and 2008, proposed strategies for unraveling student rebuttals to evolutionary theory. Rather, emphasis was placed on student inquiry, basing claims on evidence, and understanding the NOS.

Using hominid skulls: Claims made and gaps

The articles I reviewed in this section made claims regarding the utilization of 3-D hominid skulls/photographs. The authors suggested that the use of hominin skull learning experiences:

- Increased student motivation to learn;
- Increased student understandings of evolutionary theory;
- Increased student understandings of NOS;
- Increased student acceptance of evolutionary theory;
- Increased students abilities to engage in comparative anatomy;
- Increased student abilities to do inquiry;
- Addressed student misconceptions of evolutionary theory; and
- Created a contextualized environment for learning.

Since these claims were based on the authors' personal accounts of classroom phenomena, a whole area of research could be dedicated to empirically testing them. The nature of my research will address most, if not all of these claims.

Final note

This literature review has focused on the state of evolution literacy comparing the public views with normative scientific views. It has established the purpose for the teaching and learning of both evolution and human evolution, explored the most effective pedagogical strategies for teaching these topics, including the use of hominid skulls. Clear outcomes of the literature review reveal the ineffectiveness of conventional conceptual change models, and make imperative the need for conceptual change models that include both cognitive and affective domains of learning—given the complexities that arise when teaching a perceived topic of controversy like evolution (Anderson, 2007). Moreover, this review reveals the need to flesh out the optimal combination of pedagogical approaches to address both cognition and affect—toward a purported goal of understanding (Smith & Siegel, 2004). However, a more realistic goal may be to open a small window in the minds of learners—to get their feet wet—for future learning experiences in human evolution (Dewey, 1938; Meadows, 2007).

Last, the literature review revealed gaps in the evolution education research. First, few studies regarding the teaching and learning of evolution, human evolution, and/or human evolution through hominid skull replicas met standards of rigor (i.e., giving attentive descriptive detail to theory, pedagogy, curriculum, methodology, and methods). And, claims regarding positive student outcomes were also made in abstention of empirical evidence. My study attempted to fill these gaps.

Theoretical Framework

Introduction

I used social constructivism as my main theoretical lens to inform a cascade of both teaching and research theory. I chose social constructivism because it maintains precepts of individual cognitive development established by Jean Piaget (1978), while making extensions into notions of the social construction of knowledge established by Lev Vygotsky (1978). The first two sections of my theoretical perspective attend to constructivism and social constructivism separately for the sake of clarity. The second portion of this section develops the theory behind my curriculum design principles.

Constructivism

Piaget's (1978) constructivist theory assumes that individuals construct or build knowledge. These constructions occur when new knowledge interfaces with one's current conceptual framework. Assuming that each individual brings a unique conceptual framework to learning situations, newly formed constructions may be quite varied even when individuals are exposed to the same learning experience. The following two paragraphs discuss how constructivist theory informed me as a teacher-researcher and in curriculum design.

As a researcher I acknowledged that the way I constructed meaning based on classroom experiences may have differed from colleagues. We may or may not have converged on one or any single "Truths." I embraced the notion of pluralistic meanings, and relinquished any claims towards establishing "Truth" or "validity" as used in conventional positivistic research. I aspired to document descriptive accounts of classroom occurrences and gather rich data sets of student input and teacher reflection in order to recreate/communicate learning experiences as

transparently as possible to readers, and for their own freedom of interpretation. Last, I focused on the transferability and viability (Lincoln & Guba, 1985) of the research process.

As a teacher, I acknowledged that my student-participants brought unique conceptual frameworks to learning situations, making it imperative that we establish prior knowledge in order to tailor future learning, contextualize learning in what is currently meaningful or relevant to students, and provide students with ample time and scaffolds to grapple with new material through active-learning, sense-making, and intellectual engagement strategies, etc.

Social constructivism

I agreed with social constructivist theory that our individual constructions of knowledge are influenced by a larger social context; we construct knowledge through interactions with our world and innate objects (per constructivism), but also through our interactions with each other (Lave & Wagner, 1999). Research framed by social constructivism assumes that findings arise out of a community of interaction and experience. The following two paragraphs explain how social constructivism was important to myself as a teacher-researcher and in influencing curriculum design.

In line with social constructivist theory, the researcher often takes on a participant-observer role (Patton, 2001), actively and reflexively engaged with participants in research rather than objectively distanced as in the positivist research paradigm. Participant-observer most accurately represented my research role due to my privileged and prolonged access to the research setting and participants; our “community of practice” (Lave & Wagner, 1999) developed over seven months prior to the research process. I came to know participants’ personalities, strengths, weaknesses, hobbies, attitudes, family life, etc. due to this daily interaction. During the research intervention, an emic perspective allowed me to gather more

accurate and thorough observations, identify contradictory responses from participants, and detect taboo or obscure observations that might otherwise go unnoticed during snapshot (e.g., survey) research attempts.

However, I recognized that my close participation during the research process might have imposed certain biases. I may have been limited by the scope of what one researcher can notice and document, and/or may have been subconsciously partial to observing certain phenomena over others in order to support my own theories (Erickson, 1988). Recording classroom interactions, focus group interviews, and student-participant presentations, and collecting student-participant artifacts for repeated review, helped temper these research concerns (Erikson, 1988) discussed more fully in chapter three.

Social constructivism also informed pedagogy. My student-participants and I developed a community of practice in the discipline of science throughout the school year, and specifically and collectively participated in the discipline of paleoanthropology during the research intervention. Developing a science-oriented context for day-to-day interaction immersed us in the culture and language of science, and challenged us to actively approximate the work of expert scientists to discover the epistemology, skills, and knowledge of science. Smaller pedagogical decisions were also made based on social constructivism. Students often worked collaboratively (also consistent with the epistemology of science) (Chiappetta & Koballa, 2004; 2006) when completing learning experiences.

Curriculum design principles

Introduction.

The literature review at the beginning of this chapter revealed the need for a human evolution curriculum that addressed both the cognitive and affective domains of learning, with

the ultimate goal of relaying understanding (not acceptance or belief) to learners. And, social constructivism implies learning as an active and social process. Therefore, I carefully chose a mosaic of curriculum design principles attentive to these recommendations. Backwards design, situated learning, inquiry, scaffolds, explicit NOS instruction, and learning tools served as the curriculum design principles in my study. Table 2.6 organized the definitions of the six curriculum design principles and also lists their instructional components. Following paragraphs discussed the curriculum design principles and their instructional components more fully.

Backwards design.

Backwards design (Wiggins & McTighe, 1998) was the main curriculum design principle in my study, framing clear cognitive goals for learning. Backwards design turns the approach to teaching and learning upside down. Teaching and learning is approached with the end in mind; teachers and learners ask, “What do we want to know and be able to do by the end of the

Table 2.6 <i>Six Curriculum Design Principles Underpinning My Study</i>		
Curriculum Design Principle	Definition	Instructional Component
Backwards Design	A curriculum design technique of identifying objectives, designing authentic assessments, and setting capstone goals before developing the curriculum (Wiggins & McTighe, 1998).	• Essential/driving questions • Essential sub-questions • Project-Based Learning • Performance Task • Authentic Assessment
Situated Learning	Learning that occurs in a similar context in which it is applied in the real-world (Lave & Wenger, 1991).	• Discipline-specific practice • Contextualization • Relevance • Collaboration • Discourse
Inquiry	“...the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (NRC, 1996, p. 23), and a set of interrelated process skills by which scientists and students pose and systematically answer questions about the natural world (NRC, 1996, p. 214).	• Generate and investigate scientific questions • Formulate explanations based on evidence • Communicate and justify findings • Enquiry
Nature of Science	Epistemological characteristics of science include science as “tentative (subject to change), empirically based (based on	• Explicit instruction • A place to stand

	and/or derived from observations of the natural world), subjective (involves personal background, biases, and/or is theory-laden), necessarily involves human inference, imagination, and creativity (involves the invention of explanations); and is socially and culturally embedded” (Lederman, 2007, p. 833)	
Scaffolds	A series of methods that pace and organize learning experiences that would otherwise be too difficult for learners (Schunk, 1996).	• Anticipatory Set • Prior Knowledge • Alternative conceptions • Graphic Organizer • Reflection • Summarizing Activity • Formative Assessment • Summative Assessment
Learning Tools	“Tools that support students in intellectually challenging tasks” (Singer, Marx, & Krajcik, 2000, p. 167).	• 3-D Extant Mammalian Skulls • 3-D Extinct Hominin Skulls

curriculum unit?” Conceptualizing “the end in mind” considers student interests, the “big ideas” of the discipline of study, the standards to be covered, and the authentic assessments (Rule, 2006) to drive the learning process and measure learning outcomes; designing individual, daily learning experiences ensues to reach these ends. The end in mind in my study envisioned students approximating the work of paleoanthropologists—sharing reconstructed life histories of extinct hominins, and sharing hominin phylogenies in simulated peer-reviewed symposia.

Paleoanthropology in my study delivered the “big ideas” of science. Focusing on the “big ideas” transcended rote facts and isolated activity to consider broad concepts and principles of science toward “enduring value” and “enduring understanding” for students (Wiggins & McTighe, 1998, p. 23). Paleoanthropology encompassed the broader scientific concepts of inquiry, the nature of science, and evolution, serving as a vehicle to make these “big ideas” explicit and accessible to students.

Backwards design is assessment driven approach hinging on the close consideration of content standards and authentic assessment (Wiggins and McTighe, 1998). Evolution and NOS standards presented in the National Science Standards (National Research Council (NRC), 1996), state (Georgia Performance Standards) and county standards (Academic Knowledge and

Skills) where the study was conducted, were carefully scrutinized in the design of learning experiences. The standards were considered to stay true to the concepts of the scientific discipline, to maintain clarity between learning objectives and assessments, and to be fair to students taking standardized tests aligned to the standards.

Backwards design also relies on performance tasks or authentic assessments that contextualize, drive, and measure learning. Wiggins and McTighe (1998) have explained that a performance task (not to be confused with performance goals) creates “complex challenges that mirror the issues and problems faced by adults...[and] require a production or performance” (Wiggins & McTighe, 1998, p. 14). Moreover, performance tasks are “authentic” (p. 14). The definition of “authentic” activity applied in educational settings remains tentative in the literature; no activity can be truly authentic unless it transpires in an actual real-life setting. However, Rule (2006) identified four characteristics of authentic activity after an intense review of authentic assessments in higher education. Authentic activities:

1. Involve real-world problems that mimic the work of professionals,
2. Include open-ended inquiry, thinking skills, and metacognition,
3. Engage students in discourse and social learning, and
4. Empower students through choice to direct their own learning.

I used these four characteristics of authentic activity to inform the performance tasks in my research. An example of a performance task in my study challenged students to recreate the life histories of extinct hominins based on skull characters and present their findings at a peer-reviewed symposium. This performance task embodied the four criteria set by Rule above, with the exception of student choice. I adopted a more guided approach to teaching and learning,

providing students with opportunities to make some, but not all choices during the learning process, given their developmental and skill level as middle school students.

I would be remiss not to mention the importance of essential questions within the context of backwards design. Put simply, essential questions “help create a need for students to understand the how and why of a project” (Barron et al., 1998). These questions are often broad and thematic, requiring long-term, in-depth consideration. They encourage learning that is relevant to students’ lives, engender motivation that fuels the learning process, and encourages cooperative learning toward a community of practice (Singer, Marx, & Krajcik, 2000; NRC, 1996). The essential question for my students was, “How can we step into the shoes of paleoanthropologists in order to learn about science and evolution?” Sub-questions derived from overall essential question facilitated and organized student progress on a daily basis. They helped to “link learning activities back to the driving question” (Singer, Marx, & Krajcik, 2000, p. 167). For example, “What can we learn from our own skull?” served as a sub-question in my curriculum with students.

Situated learning.

Lave and Wenger’s (1991) situated learning theory also informed my curriculum design. Situated learning theory assumes that learning proceeds best when it is couched in real-world contexts, and when learners participate in a community of practice. The NSES (1996) also supported this notion, stating, “Inquiry into authentic questions generated from student experience is the central strategy for teaching science” (p. 31). Learning in my study was situated in the discipline of paleoanthropology—the study of ancient humans or hominins as found in fossil remains. Therefore, learning units and experiences were designed so that learners approximated the work of real paleoanthropologists. My students and I asked and answered

questions, and solved problems central to the discipline of paleoanthropology: what was the life history of *Australopithecus afarensis*?; how are the extinct hominins related to each other phylogenetically? Like paleoanthropologists, students first honed their skills as mammalogists—drawing, observing, and interpreting extant mammalian skulls; extant mammalian skulls became reference points for interpreting extinct hominin skulls. Subsequent inquiries challenged students to enter the extinct hominin world. They simulated hominin fossil digs, drew and observed the details of extinct hominin skull replicas, and compared these to extant skulls studied previously. Moreover, they reconstructed the life histories of these hominins and developed hominin phylogenies based on shared derived skull characters, with findings to be shared at peer-reviewed symposia.

This contextualized environment for learning encouraged a community of practice, a group of people who share common knowledge and experiences (Lave & Wenger, 1991). By participating in our community of practice, I hoped that my students would engage in the language, discourse, and practice of paleoanthropology, which would serve as a foothold for coming to know broader ideas of the nature of science and evolution (e.g., science as empirically –based, yet tentative, and human evolution based on substantial fossil evidence rather than a shaky “theory”).

Research on the application of situated learning environments has suggested both cognitive (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Rivet & Krajcik, 2008; Roth, 1995; Schwartz, Lederman, & Crawford, 2004) and affective (Barron, 1998; Blumenfeld, Soloway, Krajcki, Guzdial, & Palincsar, 1991; Reiser, Krajcik, Moje, & Marx, 2003) benefits.

Inquiry.

One of the quintessential practices of paleoanthropology, and science in general is inquiry. Thus, inquiry is also one of my main curriculum design principles. In this section, I defined inquiry from the perspective of a practicing scientist, but also from the perspective of the learner and teacher, as all perspectives intersected in my research study.

The NSES (NRC, 1996) provided primary definitions of inquiry from the scientific, student, and teacher perspectives. Additional references enhanced these primary definitions. The NSES was a result of four years of collaborative work by twenty-two scientific and science education societies and over 18,000 professionals, producing a 262 page document clarifying “inquiry” for the science education community, a critical achievement given the diverse use and application of the term in the science education literature as documented by Anderson (2000). The three perspectives of inquiry as outlined by the NSES related to my research study, and were considered in the development of learning experiences. Each perspective was developed below.

Inquiry: The scientific perspective.

The NSES (1996) defined inquiry from the scientific perspective as “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work (NRC, 1996, p. 23). The following portion of this discussion dissects the language used in this definition, specifically “diverse ways,” “natural world,” “explanations,” and “evidence.”

Science is a distinct way of coming to know through “diverse ways” or various processes, methods, and strategies. It is much more than a stagnant body of facts as presented in many science textbooks (Abd-El-Khalich, Waters, & Le, 2008.) Chiappetta and Koballa (2006)

explained, “Scientific inquiry has at least two critical aspects, the process of finding out and the product of the search” (pg. 144). This process of finding out has often been referred to as the scientific method, with a strict protocol of asking a question, making observations, stating a hypothesis, and experimenting to confirm or challenge the hypothesis (McComas, 1998). However, many great scientific discoveries resulted outside of experimentation. Simple observation and speculation revolutionized science, such as Nicolaus Copernicus’s heliocentric model of the universe and Jane Goodall and Dian Fossey’s accounts of great ape behavior. Louis Leakey’s indirect observations of extinct hominins (humans) through fossilized remains revealed insights into our human past. Thus, “science knowledge is gained through a variety of ways including observation, analysis, speculation, library investigation, *and* [italics in text] experimentation” (McComas, 1998, p. 18). Such procedural diversity should be represented in the teaching and learning of science. Studying paleoanthropology is an ideal way to learn about an unorthodox discipline of science, which relies on retrodictive inquiry, and illustrates NOS concepts such as science as tentative and changing.

The NSES defined science as a discipline concerned with examining the “natural world,” making a practical, yet philosophically fuzzy boundary for evaluating the questions science can and cannot answer. The philosopher Karl Popper (1978) provided a solution to this “demarcation problem” (Shermer, 2001)--the question of where to draw the boundary around science. Popper challenged traditional, positivist notions. He viewed science “not [as] a matter of scientists making a discovery and then proving it to be right. It is a matter of scientists making a guess and then finding themselves unable to prove the guess wrong, despite strenuous efforts to do so” (Crotty, 1998, p. 31.) Moreover, proving a theory correct was philosophically unsound, as undiscovered evidence may arise in the future to refute any claims of absolute truth. Only certain

questions (such as those dealing with the natural world) are falsifiable. For example, a modern human fossil dated to 50 million years ago would falsify our theory of evolution. Moral, ethical, and metaphysical questions, for instance, cannot be falsified. Creation science or intelligent design do not meet the falsifiability criterion as proposed by Popper, and therefore cannot be considered scientific.

The final critical phrase in the NSES definition of the scientific enterprise concerns developing “explanations” based on “evidence.” *Inquiry and the National Science Standards: A Guide for Teaching and Learning* (2000) appended the original NSES document, and explained the nature of scientific observation and explanation. Evidence is made synonymous with “observations and measurements” collected by the use of “senses, or instruments such as telescopes to enhance their senses, or instruments that measure characteristics that humans cannot sense, such as magnetic fields” (p. 26). “Explanations” are described as paths made from observation that “provide causes for effects and establish relationships based on evidence and logical argument” (p. 26).

Inquiry: The learner’s perspective.

The NSES also defined inquiry from the perspective of the learner. Content Standard A is labeled “Science as Inquiry,” and established the following learning goal: “As a result of activities in grades 5-8, all students should develop: a) abilities necessary to do scientific inquiry, and b) understandings about scientific inquiry” (p. 143). “Abilities” and “Understandings” are further defined and presented in Table 2.7.

Table 2.7 <i>NSES Science as Inquiry: Learner's Perspective</i>	
Abilities Necessary to Do Scientific Inquiry	Understandings about Scientific Inquiry
Identify questions that can be answered through scientific investigation.	Different kinds of questions suggest different kinds of scientific investigations.
Design and conduct scientific investigation	Current scientific knowledge and understandings guide scientific investigations.
Use appropriate tools and techniques to gather, analyze, and interpret data.	Mathematics is important in all aspects of scientific inquiry.
Develop descriptions, explanations, predictions, and models using evidence.	Technology used to gather data enhances accuracy and allows scientists to analyze and quantify investigation results.
Think critically and logically to make the relationships between evidence and explanation.	Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.
Recognize and analyze alternative explanations and predictions.	Science advances through legitimate skepticism.
Communicate scientific procedure and explanations.	Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods for procedures for investigation, or develop new techniques to improve the collection of data.
Use mathematics in all aspects of scientific inquiry.	

Content Standard A of the NSES defined science for learners beyond just doing science (i.e. making observations). Learners should also inquire into inquiry, to critically think about and explicitly discuss *how* science is done (i.e. how to make accurate observations, how to logically form explanations from them). Joseph Schwab, a curriculum theorist at the University of Chicago, first supported acculturating science learners into the discipline of science, moving beyond science teaching and learning as a “rhetoric of conclusions” but as an experience in what scientists do in their everyday practice. He coined this curricular approach as “enquiry” (1962) which would help students

become cognizant of science as a product of fluid enquiry, understand that it is 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” (p. 5).

Through enquiry students develop the habits of mind of scientists and come to understand “the values and beliefs inherent to the development of scientific knowledge” (Abd-El-Khalick, Bell, & Lederman, 1998)—also referred to as the nature of science (NOS). The epistemological characteristics of science include science as

tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (involves personal background, biases, and/or is theory-laden), necessarily involves human inference, imagination, and creativity (involves the invention of explanations); and is socially and culturally embedded (Lederman, 2007, p. 833).

In addition, the NOS makes explicit the difference between observation and inference and the difference between theory and law as important understandings regarding the NOS (Lederman, 2007).

Inquiry: The teacher’s perspective.

The NSES defined inquiry in terms of teaching strategies in Teaching Standards A-F (p. 30-52.) Table 2.8 lists these teaching standards.

Table 2.8 <i>NSES Inquiry Teaching Standards</i>
A. Teachers of science plan an inquiry-based science program for their students.
B. Teachers of science guide and facilitate learning.
C. Teachers of science engage in ongoing assessment of their teaching and of student learning.
D. Teachers of science design and manage learning environments that provide students with time, space, and resources needed for learning science.
E. Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.
F. Teachers of science actively participate in the ongoing planning and development of the school science program.

These six teaching strategies are broad and relate teaching and learning in general to inquiry. The NRC (2000) more specifically related science teaching and learning to the work of

practicing scientists, identifying five key features inherent in the teaching and learning of inquiry. Learners

- Are engaged by scientifically oriented questions;
- Give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions;
- Formulate explanations from evidence to address scientifically oriented questions;
- Evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding; and
- Communicate and justify their proposed explanations (NRC, 2000, p. 25).

These five features have implications for pedagogy. The learner is prioritized over a particular teaching strategy, and effective teaching is measured in terms of the learner's mental engagement in developing scientific explanations in relation to current scientific knowledge and for the purpose of communicating these explanations to others (Bybee, 2000). The NRC (2000) indicated that effective inquiry-based classroom encompass all five of these essential features of inquiry, yet the degree of learner self-direction versus direction from the teacher may vary. Figure 2.2 shows the variation of teacher scaffolding that may occur in inquiry teaching and learning, with the left column representing the most advanced forms of inquiry a learner might demonstrate.

Essential Feature	Variations				
Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source	
Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze	
Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence	
Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections		
Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to sharpen communication	Learner given steps and procedures for communication	
More ←	Amount of Learner Self-Direction				→ Less
Less ←	Amount of Direction from Teacher or Material				→ More

Figure 2.2. Essential Features of Inquiry. (NRC, 2000, p. 29). A spectrum of student involvement is shown.

Scaffolds.

In this study, I provided students with the necessary scaffolds to direct and support inquiry. The NRC (1996) supports such notion stating, “At all stages of inquiry, teachers guide, focus, challenge, and encourage student learning (p. 33). Learning scaffolds entail a series of methods that pace and organize learning experiences that would otherwise be too difficult for learners (Schunk, 1996). Scaffolding student learning involved specific research-based supports such as the use of anticipatory sets (Bean & Peterson, 1981), identifying prior knowledge and addressing alternative conceptions (NRC, 2003), graphic organizers (Griffin & Malone, 1995;

Robinson & Kiewra, 1995), reflection (White & Frederiksen, 1998), summarizing activities (Marzano, Pickering, Pollack, 2001), and formative and summative assessments (Marzano, Pickering, Pollack, 2001).

Explicit NOS instruction.

The explicit instruction of Nature of Science (NOS) concepts was another curriculum design principle. This principle was an important curricular component, as situated learning provides ripe opportunities for exploring the topic (Daugher & Boujaoude, 2005; Herman, 2008; Schwartz, Lederman, & Crawford, 2004). Second, research has suggested that fostering normative views of the NOS, has synergistic effects on the learning of evolution concepts, and can be used to help manage the conflict of teaching evolution (Meadows, 2007). The following discussion sections defines NOS, explores effective instructional strategies for relaying NOS concepts, and discusses how I used the NOS as a strategy to mitigate tensions with covering the controversial topic of human evolution.

Defining NOS.

Lederman (2007) conducted an extensive review of the literature on NOS, or epistemology of science, in the article, *Nature of Science: Past, Present, and Future*. He noted that NOS, ironically, is tentative; specific defining characteristics of this concept differ depending on the particular philosopher, historian, science educator, or time period in the history of science. However, he concluded, “there is an acceptable level of generality regarding NOS that is accessible to K-12 students and relevant to their daily lives” (p. 833). Most importantly, he explained that “students should understand the crucial distinction between observation and inference,” which would form the foundation in also understanding the distinction between scientific laws and theories (Lederman, 2007, p. 833). Other important NOS concepts stated that

scientific knowledge is “tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (involves personal background, biases, and/or is theory-laden), necessarily involves human inference, imagination, and creativity (involves the invention of explanations); and is socially and culturally embedded” (p. 833). I predominately used Lederman’s definition/characteristics of NOS in designing our NOS learning experiences. However, I also borrowed from the National Science Standards (NSS) (NRC, 1996), Benchmarks for Scientific Literacy (Benchmarks) (AAAS, 1993), and the Georgia Performance Standards (GPS, 2006) as these also focus on aspects of NOS commonly agreed upon (Smith & Scharmann, 2008).

Explicit NOS instruction.

Some researchers have suggested that one of the most effective ways to teach NOS is through explicit and reflective instructional approaches (e.g., Schwartz, Lederman, & Crawford, 2004; Lederman, 2007; Scharmann, Smith, James, & Jensen, 2005; Smith & Scharmann, 2008). They have explained that doing science or engaging in inquiry-based tasks is not enough (e.g., students making observations does not necessarily translate into understandings that science is empirically based and focused on the natural world). Students must be given ample time to grapple with and reflect on NOS concepts as they relate to science learning situations. So, the explicit consideration of NOS concepts should “be planned for instead of being anticipated as a side effect or secondary product” (Akindehin, 1998, p. 73). Smith & Scharmann (2008) provided an extensive list of pedagogical approaches suitable for explicit, reflective NOS instruction: “reflective journal writing, small and/or large group lectures and discussions, teacher questioning, science-embedded activities, card sorts/card exchange games using NOS concepts, concept mapping, analysis or critical and typical teaching incidents, presentations by visiting

expert speakers (scientists, philosophers, historians of science, classroom teachers who teach NOS etc.), debates, readings, videos, developing lesson plans that address both science content and NOS, historical case studies, and comparing positions of philosophers, historians, and sociologists of science” (p. 224). I borrowed from this list in the development of the 3-hour NOS intervention described in my methods section, and in NOS consideration sprinkled throughout discipline specific activity in paleoanthropology.

Researchers have also suggested that NOS instruction can be effective both in distinct units (e.g., Scharmann et al., 2005; Smith & Scharmann, 2008) and contextualized within authentic science experiences (e.g., Schwartz, Lederman, & Crawford, 2004). I used both strategies in my research project; the students and I experienced a distinct NOS unit prior to learning about human evolution, and we also grappled with NOS concepts in context with human evolution inquiries.

NOS and “a place to stand”.

I used an exploration of the NOS to help students “find a place to stand” (Scharmann, 1990, p. 98) in the culturally misunderstood and forbidden world of evolution we were attempting to enter. I hoped that this “place to stand” would provide a conceptual home for students—not at an extreme locus or at opposite ends of a science-religion dichotomy. This “place to stand” encouraged students to conceive of an epistemic mosaic. I hoped that in encouraging views of a pluralistic world, that students would relinquish perceived controversy and at least enter the conversation of human evolution. Anderson (2007) has agreed that comparing and contrasting the NOS with other epistemologies can effectively unhinge students from dichotomous thinking (i.e., science versus religion). Students can come to see that science and religion do not have to be perceived as two competitive forces. They are two of many ways

of knowing—two of many fabrics that make up collective understanding. Science, then, is not a threat to religious belief; its not better either, just different. I tried to relay these notions to students to help them negotiate their upbringings in our Christian conservative community, and the ideas that would emerge in our discussion of human evolution. Also, if questions of religion arose during our inquiries, I reminded students of the NOS, and that it was behind the scope of science to answer questions of the supernatural world. I hoped that clarifying the boundaries of science to include only questions of the natural world, would also help students in engaging in the learning process, rather than rejecting it completely from the start.

Learning tools: Using 3-D extinct hominin skull replicas.

Learning tools, namely extant and extinct 3-D skull replicas, were a final curriculum design principle. I used thirteen extant skull replicas and sixteen extinct hominin skull replicas purchased from boneclones.com. (Bone Clones, Inc., 2012). The skulls served multiple roles during the curriculum intervention, as scientific models, motivational catalysts, contextual artifacts, centerpieces of inquiry, and vehicles for discussing NOS and evolution content.

First, the extant and extinct 3-D skull replicas served as models, defined as “tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power” (NRC, 1996, p. 117). The skull replicas purchased from Boneclones were made from casts of actual skulls. The hominin skull replicas are actually observed by practicing paleoanthropologists, when an actual hominin fossil may be inaccessible, under lock and key, priceless and protected. And like paleoanthropologists, we used the skull models to generate our own data to develop explanations of hominin life histories and phylogenies.

Second, I anticipated that 3-D skull replicas would motivate learning both extrinsically and intrinsically. Inciting motivation was important because motivation is the “prerequisite and

co-requisite for the construction of knowledge” (Palmer, 2009, p. 1863); it’s the medium that fuels the learning process. I hypothesized that these skulls would motivate learning because students would find them novel, morbid, and linked to the myriad forensics shows they find interesting. Also, research has suggested that “touch matters” in enhancing learning experiences (Jones et al. 2006) and the tactile nature of the skulls most likely would pull students into immediate discovery. I proposed that intrinsic motivation for learning would ensue as student-generated lines of inquiry naturally unveiled.

Third, the skull provided a vehicle for understanding NOS and evolution concepts. The 3-D hominin skull replicas enhanced cognition as well. Students commented on how “it is amazing what you can learn just from a skull” (Beall, 2007). Clues to diet, locomotion, adaptations, social behavior, intelligence, etc. reside in subtle osteological features of the skull. Take the skull of *Australopithecus afarensis*, a hominin species discovered in the 1970’s and nicknamed “Lucy”. We know that her species was slightly more intelligent than a chimpanzee, given the relative size of her brain case. She ate a diet of fruit and coarse vegetation, given her large incisors, robust jaw, and flat molars. She was bipedal, walking on two legs, indicated by the centrally located hole in the bottom of the skull where the spinal cord attaches. We suspect she lived in a complex social society, because a skull representing the male version of her species was found, and his features are exaggerated (larger canines, prominent brow ridge and pronounced sagittal crest); such patterns of sexual dimorphism suggest that each gender took on separate behavioral roles in a complex social society (Fossey, 1983). In sum, the skulls gave “students a real feeling for the evidence that human evolution has occurred,” (Gipps, 1991, p.12). Students come to understand that what we know about our human past is based on observation (albeit indirect observation from fossil remains) unraveling student prior conceptions of evolution as mere conjecture—*just a*

theory (Daugher & Boujaoude, 2005; Nehm & Schonfeld, 2007). One of my students realized that “I have to believe evolution, because the skulls are facts” (Beall, 2007).

With the skulls, it was not necessary to overstate the dreaded “E” word (evolution) that can often startle students—inciting emotional responses that are often negative—and shut down learning from the start. The skulls rather than an authority figure could tell the story of evolution.

CHAPTER 3

METHODS

Introduction

This study was conducted to elucidate students' views and abilities when they apprenticed as paleoanthropologists using 3-D, extinct, hominin skulls replicas. This study was also conducted to catalogue the evolution of my own thinking regarding the teaching and learning of human evolution as I engaged in teacher research, and to develop an empirically based curriculum for the teaching and learning of human evolution at the secondary science level. The first part of this chapter explicates the research methodology (teacher research) that provided a broader framework for particular research methods and considers standards of research practice and standards of evidence. The second part of this chapter delves into the particular research methods responsible for the practical extraction of data for analysis.

Methodology: Teacher Research

Introduction to teacher research

I used teacher research as my research methodology. Teacher research has drawn on a rich history of qualitative research in anthropology, education, and social work (Corey, 1953; Eisner & Peshkin, 1990; Lewin, 1948; Spindler, 1982). Teacher research has also gained increasing visibility and influence because of its impacts on teacher education, teacher professional development, and educational policy (Rust, 2009). Cochran-Smith and Lytle (1999) defined teacher research

in the broadest possible sense to encompass all forms of practitioner inquiry that

involve systematic, intentional, and self-critical inquiry about one's work in K-12, higher education, or continuing education classrooms, schools, programs, and other formal education settings. This definition includes inquiries that others may refer to as action research, practitioner inquiry, teacher inquiry, teacher or teacher education self study, and so on, but does not include *reflection* or other terms that refer to being thoughtful about one's educational work in ways that are not necessarily systematic or intentional (p. 22).

I conducted an extensive review of the literature to identify the key theoretical features of teacher research. This review rendered a suite of common features: a) systematic, intentional inquiry, b) organic, c) cyclic and recursive, d) action oriented, e) socially constructed, and f) political. The following paragraphs explain each of the essential features of teacher research listed above, while also juxtaposing details of my own practitioner inquiry.

Teacher research as systematic, intentional inquiry

Teacher research meets standards of rigor through *systematic, intentional inquiry* (Cochran-Smith & Lytle, 1993; Cochran-Smith & Lytle, 1999; Hubbard & Power, 2003; Mills, 2003; Rust, 2009). Cochran-Smith and Lytle (1993) defined *intentional* as “planned rather than spontaneous” and *inquiry* as a process that “generates questions and reflects teachers’ desires to make sense of their experiences--to adapt a learning stance or openness toward classroom life” (p. 24). This *intentional inquiry* often emerges from a state of tension--a hostile parent-teacher conference, low parent involvement, a disruptive child, or an unsuccessful lesson attempt, etc. (Hubbard & Power, 2003). Research questions then materialize to shape subsequent efforts to reveal relevant insights and address such endemic classroom challenges.

My own teacher research followed a similar format. My moment of “tension” actually

arose outside of the classroom. I was working with a university-based professor during the summer to develop innovative curricular formats for teaching evolution and the nature of science; the curriculum utilized hominin skull replicas as a vehicle for learning about the nature of science and evolution. I became perplexed with my lack of knowledge in these central biological concepts, and could only imagine the negative effects this had on my ability to adequately teach my 7th grade life science students. I embarked on a purposeful mission to educate myself and my students. I *intentionally* developed research questions. *Systematic* research methods were developed to guide future inquiry into my research questions.

Cochran-Smith & Lytle (1993) defined *systematic* as the “ordered ways of gathering and recording information, documenting experiences inside and outside of classrooms, and making some kind of written record” (p. 24). Teachers collect data in varied ways depending on the nature of their questions and each unique classroom setting. However, each employs an organized, methodical, thoroughgoing approach, Using methods indicative of well-established research paradigms. My own research used the following data collection tools: video recordings of classroom lessons and student presentations, semi-structured focus group interviews, pre and post questionnaires, and student work samples. I analyzed the data, combing through transcripts line by line to identify themes, vignettes, and/or episodes. The pre-post questionnaires, and student work samples were analyzed either thematically or statistically. Findings were intended to be trustworthy, viable, and transferable (Lincoln and Guba, 1985), rather than valid, generalizable, and replicable as in large-scale quantitative research efforts.

Teacher research as organic

The organic aspect of teacher research refers to the natural and endemic qualities of this research methodology. For instance, teacher research occurs in natural settings and is conducted

by the practitioners in these settings. Teachers conduct research in their classrooms or principals conduct research in their schools. The primary participants in teacher research are teachers, principals, and students who have ongoing and deep experiences of classroom life. Teachers or principals are the “architects of study and generators of knowledge” who conceptualize and actualize the research process. They make a “radical shift from receivers to researchers, users to knowers, and subjects to participants” (Cochran-Smith, & Lytle, 1993, p. 2). Students, on the other hand, serve as informants, providing the necessary empirical data to improve teaching and learning. All participants are the agents of study rather than the objects of study, and their insider or emic perspectives are revealed to inform future practice.

The organic nature of teacher research is also revealed in the finer details of question formation and research methods. Research questions often arise out of classroom tensions and remain relevant to classroom problems or concerns as identified by the practitioner. So, methods shaped to answer teacher research questions move beyond describing external phenomena as in social scientific research, to help the teacher “to develop a deeper understanding about what you are doing as in insider researcher” (Patterson, et al., 1993, p. 13). The language of teacher research is given a first person voice: the teacher expresses class phenomena in terms of what *I* or *we* perceive and experience. The use of the first person voice in teacher research is appropriate given the intention to avoid separating the researcher from the research (Patterson, et al., 1993). It is an honest use of language that acknowledges the close association of the teacher researcher to the research process. Moreover, teacher research imposes certain attributes given the priority to maintaining natural classroom proceedings. For instance, methods may be non-linear and unpredictable as they are responsive to the day-to-day dynamics of the classroom life. Variables cannot be controlled as in traditional research formats. And, the priority given to

research is secondary to sound pedagogy and rests within the constraints of what is reasonable for the both teacher and student (Baumann, Shockley, & Allen, 1996).

The benefits of an organic action research methodology deal with concepts of unique perspective, viability, and transferability. The benefits of unique perspective are best explained by the voice of a practicing teacher researcher:

We teacher-researchers bring to our work an important element that outside researchers lack--a sense of place, a sense of history in the schools in which we work. Because of our presence over time at our research sites, we teachers bring a depth of awareness to our data that outside researchers cannot begin to match. We know our schools, our students, our colleagues, and our learning agendas. Our research is grounded in this rich resource base” (Hubbard, & Power, 2003, p. xiv).

As suggestive of the following excerpt, teacher researchers have an extensive level of access to the intricacies of school life, which include interconnected variables such as student personalities and abilities, parent influences on student learning, standardized testing pressures, curricular frameworks, etc. Teacher-researchers have a consummate understanding of their research setting, providing a unique perspective unmatched by other more transient observers. One downside to such emic perspective may be a lack in the ability to see things from anew, or from a different angle from one’s own personal inclinations. This is where an outsiders perspective may be useful. They may not know the “ins and outs” of classroom life, but they may see some phenomenon with a fresh lens that is less tainted by preconception and past experience (Cochran-Smith, & Lytle, 1993).

Viability and transferability are inherent features of teacher research. Viability and transferability refer to the ability of a phenomenon to grow, develop and expand (Lincoln &

Guba, 1985). Teacher research enables such activity because the research findings are relevant to the researcher's daily practice and are more likely to be applied to inform future research or improve current practice (Mills, 2003). Other teachers are also more likely to believe in the findings of fellow colleagues, possibly implementing or building on these findings (Russ, 2009). The ability of research findings to have legs and move beyond one isolated research event points to the viable and transferable benefit of teacher research.

I consider my own research efforts as organic. Research occurred in a 7th grade life science classroom in which I was the practicing teacher--well in tune with the students and context. The research originated from my own motivation to improve evolution education, and materialized in the form of three research questions. Methods were designed intentionally and systematically, yet pedagogy remained at the forefront of teacher and student efforts. Controlling some variables was not possible due the human participants. For instance, the composition of pre and post focus group participants differed; students could not make interviews as determined by my schedule due to parameters set by how to get home after the interview or how to get out of another class to meet during my planning time. Methods were also remolded from day to day. For instance, opportunities for reflective writings arose spontaneously. Finally, my research efforts have influenced my own practice as a teacher, reshaping curricular and research efforts in the years that followed. My research findings have also been imparted to other practitioners through publications, conference presentations, and workshops (e.g, Thomson & Beall, 2008) all of which have been met with interest and positive feedback--possible indications of viability and transferability.

Teacher research as cyclic and reflexive

Teacher research involves a series of flexible research cycles (Baumann, Shockley, & Allen, 1996; Mills, 2003; Mohr & Maclean, 1987; McNiff, Lomax & Whitehead, 2003). These cycles vary (Mills, 2003) but all contain the following basic benchmarks: problem identification, data collection, data analysis and interpretation, and action plan. The research process continues beyond a conclusions and implications section; findings are applied through a course of action to make educational improvements and the research cycle begins again, although revised. Mills (2003) adds that reflection, “the willingness to critically examine one’s teaching in order to improve or enhance it,” provides the driving force necessary to seek continual improvement through these cycles of research (p. 10). Berthoff (1987) also notes that teachers do not have to come up with new problems or questions to begin a research cycle. They often already have mounds of pre-existing data from which to start the research process. Berthoff (1987) coined the term “REsearch” to describe this process of “REconsidering what is at hand” (p. 30).

My study rests on five years of co-generative inquiry with my major professor and countless input from students, teachers, and educators. We have refined our curriculum through its implementation in over 40 secondary science classrooms with nearly 10,000 students, and during three summer teacher professional development workshops. Moreover, we have shared our findings at approximately 20 international, national, state, and local conferences and in *Evolution: Education and Outreach* (Thomson & Beall, 2008). My pilot study (Beall, 2007) revealed that our unique approach to teaching and learning human evolution creates a sensitive learning environment, motivates student learning, addresses alternative conceptions that serve as barriers to learning, achieves holists levels of understanding and skill, and cultivates scientific

habits of mind--in spite of the perceived conflict that keeps so many teachers from teaching the topic (Scott, 2004). From my pilot study, I recognized the need for more data collection methods in order to more comprehensively capture classroom proceedings. Next, a course of action was taken to make curricular and methodological modifications. The research cycle resumed again during the Spring of 2008. Data analysis then followed.

Teacher research as action oriented

One of the main reasons that teachers conduct teacher research is to address classroom issues in order to take action toward improvement and positive change (Bauman, Shockley, & Allen, 1996; Mills, 2003; Mohr, & Maclean, 1987; Patterson, et al., 1993, Somekh, 2006; McNiff, Lomax, & Whitehead, 2003). The action is informed because it is empirically based, committed because there is follow through to improve conditions, and intentional because it is driven by purpose (McNiff, Lomax, & Whitehead, 2003). In this sense, the research process becomes an “intervention” in itself whereby findings are directly and intentionally applied for the purpose of progress (Somekh, 2006, p. 1). Findings in teacher research may be applied to a teacher’s own personal pedagogical practices, move beyond the teacher to improve whole classroom curricular or procedural components, or extend to the greater educational community to influence other practitioners, university researchers, and educational policy. Either way, the research efforts create momentum for action and change.

Action has been taken as a result of my own research efforts. At a personal level, my research efforts have changed my own thinking about how to deliver concepts of Nature of Science and evolution to 7th grade science students. For instance, curricular components have been modified to promote students understandings of the nature of science before concepts of evolution are introduced, and to explicitly address major misconceptions of evolution instead of

just exploring established knowledge of the topic. The classroom dynamics as a whole have also changed to place more responsibility on the students during the learning process. My teacher research has helped me to see that conceptual change occurs most freely when the students approximate the work of paleoanthropologists and when they have choice and responsibility in the learning process. So, new curricular approaches have students simulate fossil digs, observe fossil finds and present to the class, and choose their own topics of interest to research and share. Other teachers and practitioners have been influenced by my research efforts; a science teacher across the hall adopted the nature of science and evolution curriculum to implement in her own classroom. Publications, workshops, and conference presentations have also helped disseminate what has been learned to the larger educational community.

Teacher research as socially constructed

Teacher research does not occur in isolation of social context or community (Cochran-Smith, & Lytle, 1993). Research questions, for instance, often arise out of the community of the classroom, conversations with fellow teachers, and experiences in workshops or professional development classes. The research process itself intricately connects teachers, students, principals, parents, and university professors in various relationships and conversations that give the important insights for change. Moreover, the insider perspective of a teacher and the outsider perspective of a university-based researcher can enhance one another.

Somekh (2006) explained that such a relationship “promotes equality between researchers from outside the site of practice and practitioner-researchers from inside, working together with the aspiration to carry out research as professionals, with skillful and reflexive methods and ethical sensitivity” (p. 1). My own research has been/is socially constructed. Five years of collaboration with fellow teachers provided much food for thought in developing

effective teaching and learning strategies for nature of science and evolution concepts. The actual intervention curriculum was collectively and continually developed by myself, and by my major university professor. My major professor and I have shared our curricular resources and experiences with colleagues at workshops and conference presentations, which have further enriched the conversation and provided important feedback for change. My major professor has definitely provided “important insights about the framework of reference that exists outside of the research setting, and [has been] that important link to help facilitate change beyond the research setting and into the larger professional setting” (Somekh, 2006, p. 8). I have to recognize my students as well because their voices have also been heard in the process to perfect how the NOS and evolution are taught in 7th grade life science classrooms.

Teacher research as political

McNiff, Lomax, & Whitehead (2003) argued that teacher research is an inherently political endeavor because the status quo is often questioned and action is taken to promote change. My teacher research met these criteria by:

- Emancipating the voices of teachers and students, as they were the agents of the research process. Teacher research relegated the power and decision making to those who are by tradition, marginally given a voice during the research process.
- Promoting insider, practitioner knowledge and teacher agency; teachers as researchers were not supported during the “No Child Left Behind Act” with its emphasis on scientific rigor modeled after a medical research methodology (Cochran-Smith, & Lytle, 2006; Slavin, 2002).
- Teaching the topic of human evolution to middle school students; I found no middle school curriculum in my literature searches centered on human evolution

- Teaching the topic of human evolution amidst the ongoing evolution-creation controversy that continues to play out in religious, educational, political, and judicial arenas (Scott, 2004; The Talk Origins Archive).
- Seeking to take action beyond the endpoint of publication. My findings will inform future workshops, conference presentations, curriculum interventions, etc. employed by myself, my major professor, and others who tack onto our project.

This section completes a conversation of teacher research applied to my study. The next section will focus on the common criticisms of teacher research, and rebuttals to these critiques.

Criticism of teacher research

The commentary regarding teacher research is not without its critics. Much criticism comes from the academy, and is subdivided in the literature as the knowledge, methods, political, and personal and professional development critiques (Cochran-Smith, 2006; Cochran-Smith & Lytle, 1999):

The knowledge critique attacks teacher research on an epistemological level. This critique draws a distinction between formal knowledge (real knowledge) generated through positivistic methods and a mentality of “technical rationality” (Anderson & Herr, 1999, p. 13), versus practical knowledge (mere craft knowledge) generated through practitioner inquiry. Academics do not agree with the assumption that practitioners are “knowers” of their own contexts, capable of producing transferable, viable “Knowledge” (with a capital K). They are generally comfortable with teacher research as long as it is applied to the organic context in which it was generated. Skepticism arises when dealing with epistemological frameworks unlike those validated at the university level and when such research transcends the local setting to include a larger audience.

The methods critique attacks teacher research on a methodological level. Teacher researchers are perceived as unskilled and lacking enough time for “Research” (with a capital R). Critics also claim that teacher researchers are too close to their research, which engenders bias and prevents trustworthy findings. Moreover, findings are labeled as idiosyncratic, preventing the assimilation of data to achieve large sample sizes and for the purpose of generalizability--prerequisites if findings are to be useful in policy making. Overall, teacher research is discounted, as it does not meet the methodological standards as defined by the academy.

The political critique presents two antithetical arguments. The first contends that some teacher research fails to achieve its emancipatory goals or affect political agendas, while the second contends that teacher research strays into activism or advocacy.

The personal or professional development critique conceptualizes teacher research as a mode of personal and professional development rather than as a means for knowledge construction. Some forms of teacher research are also perceived as too personalized and too focused on self rather than on concrete evidence to improve larger issues in education.

Critiques of teacher research: A rebuttal

The critiques enumerated in the previous section are rooted in epistemological, philosophical, methodological, political, and social concerns. However, these concerns have been met by several counter-arguments.

Anderson and Herr (1999) provided a rebuttal to the knowledge and political critiques of teacher research. He illuminated why sects of the academy have been reticent to accept teacher research as a valid research paradigm; the unique features of teacher research (i.e. emic perspective of the researcher, the priority of praxis) are perceived as foreign, creating a tension that threatens the legitimacy and institutionalized ways of knowing of the university. And,

legitimizing “insider knowledge” might in turn threaten “outsider knowledge” at the top of university structures of power and influence. Defining teacher research as mere personal and professional development may in some ways be a political power play to maintain the status quo of conventional educational research.

Advocates of teacher research, on the other hand, have rejected the dualism between formal (outsider knowledge) and practical (insider) knowledge (Roth, 1995). Instead, insider knowledge has been given credibility because teachers “go native” everyday, which gives them privileged access to “near experience” (Roth, 1995), research settings, participants and the “hidden transcripts” (Anderson & Herr, 1999, p. 18) that may go unseen by the outsider. The rich data sets and rich descriptions that emerge render findings that are viable and transferable to other practitioners and everyday practice.

Teacher research has addressed the downsides of conventional education research. The emphasis of teacher research has focused on the collection of rich data sets and rich description as in qualitative research, rather than on snapshot methods (e.g., multiple choice pre/post measurements, questionnaires) indicative of positivistic, quantitative research methodologies. The benefits of positivist research methodologies have included cost efficiency, large sample sizes, statistically significant results, the identification of causal relationships, etc. (Slavin, 2003). However, controlled experimentation applied to teaching and learning might have been rendering fruitless results; the complexities of teaching and learning have been too great to isolate and control variables, set up double blind experiments, take on large sample sizes, etc. (Olson, 2004). Moreover, findings of large-scale education studies have often been inaccessible, unusable, and/or irrelevant to practitioners’ particular education settings (Reeves, 2011). I argue that

teacher research offers a viable solution to the gap between educational research and everyday practice.

Qualitative Research and What Counts as Data

Qualitative data includes the “rough materials researchers collect from the world they are studying” (Bogdan & Biklen, 2006, p. 117). The “rough materials” in my research included questionnaires, field notes, memos, video of classroom proceedings, video of student presentations, student artifacts, interview transcripts, classroom talk, and student presentations. This data arose from social interaction in the classroom between my students and myself and outside the classroom between myself, colleagues at conferences and workshops, and professors at my local university. All participants, either directly or indirectly involved, brought their own worldviews to the research setting, serving as various filters for their contribution to or interpretation of the data. Therefore, the data was co-constructed, rendered through various perspectives, and reconstructed when it was analyzed through my interpretive lens—no matter how much I attempted to reach sure objectivity. As Freeman, deMarrias, Preissle, Roulston, and St. Pierre (2007) have explained, “There are no “pure,” “raw” data, uncontaminated by human thought and action, and the significance of the data depends on how material fits into the architecture of the corroboration data” (p. 3).

Although I relinquished the idea of obtaining, “pure” and “raw” data, I heeded standards of research quality and evidence in order to approach as best as possible, valid answers to my research questions. I define validity as “the trustworthiness of inferences drawn from data” (Eisenhart & Howe, 1992, p. 644).

Standards of Research Quality and Evidence

In this section, I explained the standards of research quality and evidence guiding my own research, beginning with a consideration of the nature of teacher-research in framing such standards. Then I considered a framework for assessing the validity of my research during the final chapter of my study.

As a teacher-researcher, I honestly conceded to the close relationship between teacher researcher, student-participants, curriculum, and classroom research setting. I was inextricably connected. I also relinquished the notion of a controlled experimental setting with the purpose of producing generalizable findings. Anyone who has taught middle school understands its natural imperfections for conventional research paradigms (e.g., the school day schedule imposes time constraints, standardized testing looms over professional freedoms, classroom interruptions are commonplace, no two classrooms are demographically the same, students get sick and miss class, teaching and administrative responsibility compete with teacher-research responsibilities, etc.).

Therefore, I reframed my research purpose to render rich descriptions of discourse and experience among participants (including myself), understanding that these descriptions seamlessly linked to the unique time, place, people, and curriculum of my 7th grade classroom; replication and prediction became inappropriate—the claims I made were based solely on my classroom setting. I kept central the guiding question of qualitative research: “How can we best listen to, work with, and represent the people our work is intended to serve” (p. 6). I considered how to “best listen to, work with, and represent” my students—with the benefit of rich, honest description, but sometimes at the expense of one more standards of evidence. And the overall purpose of my research was to “generate useful, informational, and thought-provoking feedback

or knowledge to relevant and interested communities of scholars and practitioners” (Freeman, deMarrias, Preissle, Roulston, and St. Pierre, 2007, p. 6)

Freeman et al. (2007) discussed what constitutes research quality or competent work. These standards included “attention to (a) thorough description of design and methods in report, (b) adequate demonstration of the relationship of claims to data, and (c) thoughtful consideration by the researcher of the strengths and limitations of the study” (p. 4). I used these standards to guide my own research practice. I thoroughly described various aspects of my research such as the curriculum design principles, pedagogical choices, construction and implementation of learning experiences, limitations, challenges, and data collection and analysis methods—all in order to “enhance” and “demystify” the study (p. 4). I made transparent the relationship of data to claims by including extensive amounts of rough data, such as student quotations and transcripts of presentation and interviews, in order to share this data to readers for their own interpretation and examination. Data was only withheld if it was redundant or stepped on participants’ rights to anonymity. Last, I thoughtfully considered the strengths and limitations of my study throughout the scope of the research process and shared these considerations frequently.

Freeman et al. also discussed standards of evidence based on the work of other scholars. They cited Wilson (1994) who proposed that “evidence should be consistent with a researcher’s chosen epistemology or perspective” (p.26), “evidence should be observable” (p. 28), “evidence should be gathered through systematic procedures” (p. 29), “evidence should be shared and made public” (p. 30), and “evidence should be compelling” (p. 30). Freeman also cited Lincoln (2002) who argued that, “researchers should have been deeply involved and closely connected to the scene”, “researchers should achieve enough distance from the phenomenon to permit recording

action and interpretations relatively free of the researcher's own stake" and "claims should be based on an adequate selection of the total corpus of data" (Lincoln, 2002, p. 9). Freeman et al. also included working with other researchers using multiple methods of data collection, and peer review as additional supports for high standards of evidence. I heeded these practices in my research, attending to them at all times and describing them in this chapter.

However, I did not attend to some effective methods for high standards of evidence including member checking, working in research groups toward inter-rater reliability when analyzing data, and controlling the student composition of pre and post focus group interviews and student presentations. Some of these shortcomings were due to my own shortsightedness as a fledgling researcher. Others were due to the constraints of schooling and demands of teaching over researching—discussed more fully in the context of this chapter.

Anderson and Herr (1999) and offered suggestions for assessing the validity of teacher research that were also useful in my study. They argued "that teacher research be held to different (not lesser) standards of rigor compared to more traditional qualitative paradigms; in the same vein that form fits function, teacher research should have its own unique standards of rigor given its own unique epistemic scaffolds. Therefore, *outcome*, *process*, *democratic*, *catalytic* and *dialogic* validity should be used to assess the quality of teacher research as explained below:

1. *Outcome validity* assesses the extent by which the practitioner researcher answered their original question or solved their original problem.
2. *Process validity* assesses the extent in which the research was produced through a series of reflexive, recursive cycles--each adjusting and improving upon the next. Process validity also assesses the strength of evidence given in terms of triangulation.

3. *Democratic validity* assesses the extent in which multiple voices were used in the data collection process and analytic process.

4. *Catalytic validity* assesses the extent in which the research catalyzes thinking, discourse, action and future inquiry.

5. *Dialogic validity* assesses the extent in which the research passed through a process of peer review (Anderson and Herr, 1999).

These five aspects of validity were considered after my research was conducted as a framework for reflecting on the trustworthiness of my data and its overall potential for impact.

Research Questions and Definitions of Key Terms

Research Questions

I posed seven research questions, subsumed under either the a) affective domain, b) cognitive domain, or c) teacher reflection domain. One research question was subsumed under the affective domain:

1. What affective outcomes are expressed when students apprentice as paleoanthropologists?

Four research questions were subsumed under the cognitive domain:

1. What student views of the Nature of Science are communicated after a distinct, NOS scaffolding unit?,
2. What student views of the Nature of Science are communicated as they apprentice as paleoanthropologists?,
3. What student abilities of inquiry are demonstrated as students apprentice as paleoanthropologists?,

4. What student knowledge of hominin evolution is communicated as students apprentice as paleoanthropologists?, and
5. What student understandings of hominin evolution are demonstrated as students apprentice as paleoanthropologists?

Two research questions were subsumed under the domain of teacher reflection:

6. How do my conceptions of teaching and learning of hominin evolution change during the study as I engage in teacher research?
7. How should the curriculum intervention be modified based on teacher and student data sources?

Definitions of Key Terms in Research Questions

Below, I provide definitions for the key terms in my research questions:

- Affective domain-The domain of learning that revolves around a learners' motivation, attitudes, self-efficacy, emotions, and experiences (Dole & Sinatra, 1998; Sinatra, Brem, & Evans, 2008),
- Cognitive domain-The domain of learning that revolves around the learners' knowledge, comprehension, and critical thinking of a particular topic (Bloom, 1994; Dole & Sinatra, 1998, Krathwohl, 2002),
- Teacher reflection-The act of a teacher studying their own pedagogical practices to determine what works best, and then taking action based on this study to improve teaching and learning (Schön, 1983),
- Knowledge-An aspect of cognition that includes a) factual knowledge, knowledge of terminology, details, and elements, b) conceptual knowledge, knowledge of the interrelationships among the basic elements, c) procedural knowledge, knowledge of

inquiry in the case of science education, and d) metacognitive knowledge, knowledge of one's own cognition (Bloom, 1994; Krathwohl, 2002),

- Understanding-An active process of demonstrating “four (admittedly overlapping) criteria...connectedness, sense-making, application, and justification (Smith & Siegel, 2004, p. 563),
- Nature of Science-The epistemological characteristics of science that include science as “tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (involves personal background, biases, and/or is theory-laden), necessarily involves human inference, imagination, and creativity (involves the invention of explanations); and is socially and culturally embedded” (Lederman, 2007, p. 833),
- Inquiry-“...the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (NRC, 1996, p. 23), and a set of interrelated process skills and abilities by which scientists and students apply to pose and systematically answer questions about the natural world (NRC, 1996, p. 214).
- Paleoanthropologists-Scientists who study our human ancestry based on fossil hominid evidence (Gibbons, 2006).
- Hominin-A taxonomic group including *Homo sapiens* and their extinct ancestors that all have the shared and derived characteristics of bipedalism and reduced canines (Woods & Lonergan, 2008).
- Teacher research-A research methodology with the following set of characteristics: a) systematic, intentional inquiry, b) organic, c) cyclic and recursive, d) action oriented, e)

socially constructed, and f) political (Cochran-Smith & Lytle, 1993 & 1999; Hubbard & Power, 2003; McNiff, Lomax, & Whitehead, 2003; Mills, 2003; Somekh, 2006).

Setting

This study transpired in a 7th grade, gifted education, life science classroom in the Southeastern United States. Although the development of the curriculum intervention of this study occurred over several years, the data collection process occurred within one school year. The middle school rests in the suburbs of a major U.S. city and serves students from diverse demographics (43% girls; 30% minority; 60% free and reduced lunch). However, data were collected in two gifted education classes, resulting in a less diverse sample (53% girls; 17 % minority; 12% free and reduced lunch) than the overall school population. The student-participants comprised two separate classes, with one class including 20 students and the other including 19 students. All data collection efforts transpired within the student-participants' life science classroom. Additional school-day experiences for students included visits to homeroom class, three other core classes (math, social studies, and language arts) and one connections class (e.g., physical education, orchestra, band, chorus, art).

Participants

Student participants

A total of thirty-four 7th grade, gifted education students participated in this study. All students gaining written parental consent as required by the University Internal Review Board participated in the study. No additional sampling methods were applied in order to gain as much student input as possible and toward the end goal of data saturation (Charmaz, 2006).

Teacher Researcher: Participant Observer

I (the teacher researcher) brought four years of undergraduate study in biology, two years of master's level study in science education, and four years of doctoral study in science

education to the research project. I often took on the role of participant observer during classroom learning experiences, not in a student role, but in an adult role as the teacher in the classroom. The teacher-researcher role constituted participant observation because I developed an emic perspective, a perspective in which “the participant observer not only sees what is happening but feels what it is like to be a part of the setting or program” (Patton, 2002, p. 268), I also developed a close-working relationship with the student participants (Patton, 2002) eight months prior to the research study and during the research study. However, I recognized that the degree of participant observation was tempered due to my teacher role compared to taking on a full student-participant role. My extra-curricular work in a Ph.D. program also tempered my role as participant observer; I was aware of my outsider perspective while analyzing data. I took Patton’s (2002) suggestion to “combine participation with observation so as to become capable of understanding the setting as an insider while describing it for outsiders” (p. 268). The strengths of being a participant observer include having prolonged and privileged access to my research setting and student voices. However, my role as a participant-observer, may have prevented me from seeing phenomena from anew, such as would be achieved by an outside observer.

Subjectivity Statement

My previous research experience includes both qualitative and quantitative studies. I have conducted two quantitative studies related to biology. I assessed the water quality of Yahoola Creek in Lumpkin County during my undergraduate education. Quantitative data collected regarding turbidity and nutrient loads were examined after episodes of rain to determine the health of the watershed and the feasibility of Yahoola Creek as a feeder for a water

reservoir. I also conducted quantitative research as a part of my master's research in science education to establish the relation between salamander snout-vent lengths to habitat preferences in the upper Soque River. A qualitative study entitled, "The Effects of Using Technology as a Constructivist Tool in an Eight-Grade Science Classroom" was also conducted during my master's coursework and as a part of my student teaching experience.

Thus, I have had experiences conducting both qualitative and quantitative research. These experiences were beneficial in reference to this research project for several reasons. First, past experiences in research have contributed to my development as a researcher in terms of understanding the nature of inquiry and being equipped with tools to adapt during the research process. Second, past experiences in research contribute to my ability to develop a methodology and methods for this current study. On the flip side, these past experiences in research may inhibit my ability to *see* anew. For example, the famous anthropologist Louis Leakey commissioned three women (Dian Fossey, Jane Goodall, and Birute' Galdikas) with no science research background to study the great apes in an attempt to better understand human origins. Leakey's rationale behind doing so was that first, he saw that women were patient and thus better suited for field work, and second, that these women would make objective observations that would not be influenced by preconceptions. Thus, my own knowledge of research and of the science education research literature may influence the observations that I make and the conclusions that I draw from these observations.

My perspective regarding this research is not only shaped by previous experiences in research, but also shaped by my experiences as a science teacher, Ph.D. student, and my view on the creationist-evolution debate. Aspects of my perspective may prove beneficial or harmful in light of obtaining valid results. Five years as a life science teacher may have proven beneficial

when conducting this study. First, taking on a teacher-research role provided prolonged and privileged access to the research setting, enhancing the potential for emic perspective. Moreover, experiences working with students and teachers may have helped me to establish a rapport with participants, creating a comfortable environment for asking probing questions, seeking clarification, and eliciting honest responses. I may have also been more adept at *stepping into the shoes* of the participants and recording their perceptions, as I am fluent in the jargon of the life science curriculum and the middle school student. However, I needed to be aware of my preconceived notions and expectations for teaching and learning outcomes, and try to take a phenomenological approach in which I “set aside all previous habits of thought, see through and break down the mental barriers which these habits have set along the horizons of our thinking...to learn to see what stands before our eyes” (Husserl, 1931, p. 43). However, I may have been too close to my research situation to gather data free of my own preconceptions.

In addition to being a science teacher, I also participated in a Ph.D. program in science education during this study. This graduate education was beneficial as it placed me on the cutting edge of curriculum development, science education, and research methodology. This education helped in my development of a salient and sound research study. However, because of this education, I may have approached the research setting with certain assumptions, which may have influenced the lens through which I saw and observed. My own work as a student, involved the development of the curriculum employed in this study. Being well versed in regard to the components of the curriculum intervention may have been beneficial; however, as a Ph.D. student seeking dissertation material and in light of the personal investment of time and energy, I had a stake in the success of the curriculum and the research study as a whole. The stake I had in the successful outcome of the study may add to the subjectivity of this research.

Moreover, I approached this study from the viewpoint of a person raised in the southern United States and immersed in the southern culture of conservative politics and the literal Christian interpretation. I am familiar with the cultural variables that influenced the participants and classroom, which may have allowed me to effectively interpret and communicate classroom phenomenon. However, my education in the hard sciences, liberal political leanings, and agnostic religious leanings may have prevented me from being an unbiased observer.

In sum, I realized as a teacher-researcher that I brought my own set of assumptions and perspectives to the research setting. Concepts discussed earlier influenced the lens through which I saw, observed, and interpreted. Thus, I acknowledged that my own world-view may have influenced the data I chose to collect and how I interpreted this data. However, I attempted to be as objective as possible when collecting data. And, acknowledging my own subjectivities and making them transparent to readers, helped to objectify the research process. Objectivity is approached because I am honestly explaining my own world-view and how this may interplay with the research. Second, I assumed that the students who I worked with, also brought their own individual assumptions to the classroom. This second layer of perception added additional dynamics and variables when attempting to answer the research questions. These differing perspectives were considered when identifying and analyzing research themes.

Curriculum Intervention

The curriculum intervention transpired over twenty class periods (four school weeks), each class period lasting approximately 55 minutes each. Overall, the curriculum intervention situated learning in the practice of paleoanthropology; students were challenged to approximate discipline-specific practice as paleoanthropologists by studying extinct 3-D hominin skull replicas. However, the careful planning and implementation of three learning units (and the daily

learning experiences comprising these units) occurred to prepare students for this discipline specific practice and final performance tasks.

The three learning units included one focused on the NOS, one focused on extant skulls, and one focused on extinct skulls. Each learning unit provided conceptual scaffolds for experiencing the one to follow. All three learning units of the curriculum intervention were framed by one essential question, “How can we step in the shoes of paleoanthropologists in order to learn about science and evolution?” This essential question helped to organize daily learning experiences, which were also framed by sub questions useful for driving and organizing learning into more manageable pieces. Table 3.1 displays the three major learning units, their composite learning experiences, and the related sub questions.

Table 3.1 <i>One Essential Question and Ten Sub-questions Drove Instruction</i>		
Learning Units	Learning Experiences	Essential Question/Sub-Questions
All Units	Essential question	How can we step into the shoes of paleoanthropologists in order to learn about the nature of science and evolution?
NOS Learning Experiences	1. NOS Pre/Post Test	How does science compare and contrast with other disciplines?
	2. Comparing Science and Football	How does science compare and contrast with football?
	3. Which Lens is Best?	What questions can science answer?
	4. To Be or Not To Be Science?	What are the characteristics of science?
Extant Skull Learning Experiences	1. Human Skull Exploration	What can we learn from our own skull?
	2. Gorilla Skull Exploration	What can we learn from gorilla skulls?
	3. Extant Skull Drawings	What can we learn from extant mammalian skulls?
	4. Extant Skull Presentations	What can we learn from each other about extant mammalian skulls?
Extinct Hominin Skull Learning experiences	1. Evolution anticipation guide	What do we know about evolution?
	2. Hominin Fossil Dig	What is it like to go on a fossil dig?
	3. Hominid Dichotomous Key	How do we use a dichotomous key to identify the species of our fossil hominin discovery?
	4. Hominid Skull Drawings	What can we learn about our hominin skull?
	5. Hominid Skull presentations	What can we learn from each other about hominin skulls?
	6. <i>Lucy</i> film	What can we learn from <i>Lucy's</i> story?
	7. Wall of Asterisks	What does one million years look like?
	8. Hominid Hallway Phylogeny	How can we create a hominid phylogeny showing evolutionary relationships, using our 3-D skulls to show evolutionary relationships?
	9. Justifying Hominid Phylogenies	What evidence can you provide to justify your hominid phylogeny?
	10. Independent Research	What questions did you pose about your hominin fossil find and what did you learn?

The curriculum employed (Thomson & Beall, in preparation; Thomson & Beall, 2008) was theoretically framed by six curriculum design principles: backwards design (Wiggins & McTighe, 1998), situated learning (Lave & Wenger, 1991; Crawford et al., 2005), inquiry (NRC, 1996; AAAS, 1993), scaffolds (Reiser, 2004; Sandoval & Reiser, 2004), explicit attention to Nature of Science concepts (Schwartz, Lederman, & Crawford, 2004), and learning tools (e.g., 3-D extinct hominin skull replicas).

These six curriculum design principles informed the “big ideas” of the curriculum, down to the daily pedagogical details. Table 3.2 juxtaposed the six curriculum design principles and the daily learning experiences described more fully later on in this chapter.

		Essential Question	Performance Task	Discipline-specific	Relevance	Collaboration /Discourse	Inquiry	Anticipatory Set	Identifying Prior knowledge	Graphic Organizer	Summarizing Act.	Formative Assess.	Summative assess.	Address alternative conceptions	Explicit NOS instruction	A place to stand	3-D skulls
NOS	NOS Pre/Post Test	X						X	X	X	X	X	X	X	X	X	
	Comparing Science and Football	X			X	X		X	X	X		X		X	X	X	
	Which Lens is Best?	X			X						X	X		X	X	X	
	To Be or Not To Be Science?	X				X				X	X	X		X	X	X	
Extant Skull	Human Skull Exploration	X		X	X	X	X		X	X		X					
	Gorilla Skull Exploration	X		X	X	X	X		X	X	X	X		X	X		X
	Extant Skull Drawings	X		X	X	X	X			X	X	X			X		X
	Extant Skull Presentations	X	X	X	X	X	X					X	X				X
Hominid Skulls	Human evolution anticipation guide	X						X	X	X	X	X	X	X	X		
	Hominin Fossil Dig	X		X		X	X				X	X		X	X		X
	Hominin Skull Drawings	X	X	X	X	X	X			X	X	X			X		X
	Hominin Skull presentations	X	X	X	X	X	X					X	X				X
	Lucy film	X		X		X	X			X	X	X		X	X		
	Wall of Astericks	X			X	X				X	X	X		X			
	Hominid Hallway Timeline	X	X	X	X	X	X			X	X	X		X	X		X
	Justifying Hominin Phylogenies	X	X	X	X	X	X			X	X	X	X	X	X		X
	Independent Research	X	X	X	X	X	X				X		X				

Data collection occurred intermittently and frequently through the three learning units.

The data collection methods included a pre and post NOS questionnaire, a pre and post evolution questionnaire, pre and post focus group interviews, three performance tasks, video of classroom

proceedings, and teacher reflective notes. Table 3.3 showed when data collection occurred in reference to the implementation of daily learning experiences. The next section explains the rationale behind each learning experience employed, and chronicles the details of implementation.

NOS Learning Experiences

I decided to preface the human evolution unit with two distinct scaffolding or frontloading units: a) one designed to explicitly grapple with the Nature of Science (NOS), followed by b) one focused on extant skulls and comparative anatomy. This section focuses on the NOS unit. The first portion of this section reviews NOS learning experiences prior to the research intervention, examines the rationale for teaching NOS prior to teaching human evolution, and shows how NOS concepts addressed in my curriculum intervention correlate to local, state, and national standards. The second portion of this section explicates the four NOS learning experiences employed over 3 hours of instructional contact time with my 7th grade life science students.

Table 3.3 <i>Overview of Data Collection Methods</i>				
Unit	Learning Experiences	Data Collection Method		
NOS Learning Experiences	NOS Pre/Post Test	NOS pre-questionnaire	Teacher Reflections	Video Recordings of Classroom Proceedings
	Comparing Science and Football			
	Which Lens is Best?			
	To Be or Not To Be Science?			
		NOS post-questionnaire		
Extant Skull Learning Experiences	Human Skull Exploration			
	Gorilla Skull Exploration			
	Extant Skull Drawings			
	Extant Skull Presentations	Extant Skull Performance Task		
		Pre focus group interviews		
Extinct Hominin Skull Learning experiences	Anticipating Evolution			Student Work Samples
	Hominin Fossil Dig			
	Hominin Skull Drawings			
	Hominin Skull presentations	Extinct Skull Performance Task		
	Wall of Asterics			
	Hominin Hallway Timeline			
	Creating Hominin Phylogenies			
	Justifying Hominin Phylogenies	Performance Task		
		Post focus group interview		

NOS learning experiences prior to the research intervention

My students and I experienced much NOS learning throughout the year, predominately by blending NOS and inquiry-based learning. For instance, we began the school year with a 15-hour NOS unit couched in the work of Dian Fossey (Fossey, 1983). Students stepped into the shoes of Fossey to uncover the mysteries of the mountain gorilla. More importantly, we examined how Dian's work countered many alternative conceptions of science (i.e., science as objective, static, unimaginative, and derived through a strict scientific method). Other NOS learning experiences transpired during more conventional controlled experimentation (such as the egg experiment which explored how different liquids affected the mass of an egg toward understandings of osmosis). The NOS concepts explicitly discussed in these contexts included science as empirically based yet also reliant on inference, imagination, and creativity. Overall, we taught and learned NOS concepts throughout the year, so I expected that my students would

bring some normative views of NOS to the research situation given their past experiences in our classroom.

NOS learning experiences before human evolution learning experiences: A rationale

Although my students and I explored the NOS throughout the year, I thought it necessary to explicitly discuss the concept again in a separate and distinct way prior to exploring the concept of human evolution as practiced in several successful research attempts (e.g., Crawford, Zembal-Saul, Munford, and Friedrichsen, 2005; Scharmann, Smith, James, & Jenson, 2005). This decision rested on two major reasons: (a) students often perceive the evolution-religion dynamic as a black and white, dichotomous, right or wrong, and/or controversial issue which can interfere with learning (Alters & Nelson, 2002) (Table 3.4), and (b) students' often use faulty views of NOS to discredit evolutionary theory (Daugher & Boujaoude, 2005) (Table 3.5). I expanded on each of these two reasons below.

Students' worldviews can be so discordant with the scientific worldview, that learning science becomes an act of cultural "border crossing" (Aikenhead, 1999), and especially if the topic is perceived as controversial (Sinatra, Southerland, McConaughy, & Demastes, 2003). Consistent with worldview theory and others (i.e., constructivist, social constructivist, socio-cultural, and current conceptual change theory), I decided that I must consider my students' worldviews in the development of a unit on human evolution. After all, our school was located in a small Southeastern town with a mega-Baptist church as the centerpiece of community. Many of my students likely held worldviews steeped in literalist, conservative, Christian traditions. Human evolution might lie in stark contrast to their notions of Truth—a world divinely

conceived, governed by constancy, simplistic, with man taking a special place in nature.

Culturally border crossing into discussions of human evolution might be impossible for some of these students without concerted efforts to ease the transition.

Table 3.4 <i>Students' Dichotomous Views of Evolution</i>	
Dichotomous view	Reference
One has to either believe or not believe in evolution.	Anderson, 2007
If one accepts evolution, then they are atheists.	Anderson, 2007; Jackson, Doster, Meadows, & Wood, 1995
If one accepts evolution, then they are immoral.	Jackson et al., 1995
Evolution is a black or white, yes or no issue.	Anderson, 2007

Suggestions for mitigating tensions regarding the evolution-creation dichotomy have been offered in the science education literature. I considered those approaches focused on “managing the conflict” (Meadows, Doster, & Jackson, 2000, p. 106; Neslon, 2000; Alters & Alters 2001). Such approaches maintain high commitments to science theory, while also maintaining respect for students’ religious beliefs. Jackson (2000) and Scharmann (1990) suggest instructional approaches that examine the evolution/creation controversy. However, these approaches were employed with pre-service or undergraduate students and in a University setting with greater professional freedom. I was working in a state-funded institution, bound by specific teaching and learning standards (GPS) and required to uphold the separation of church and state. I also worked with minors. I decided that religious discussion was better left to parents and in the setting of the home. Therefore, I avoided evolution-creation discussion in the classroom despite identified benefits such as increasing student acceptance and attitudes toward evolutionary theory (Scharmann, 1990) and building an environment of respect and understanding (Jackson, 2000, Jackson et al. 1995; Smith & Scharmann, 2008).

I decided to refocus my students on NOS, and how science compares and contrasts to other epistemologies as suggested by Anderson (2007). In essence, I wanted students to consider

an epistemic mosaic, using the assemblage of students' everyday experiences in their content classes to create a conceptual image of how we come to know. I challenged students to explicitly consider the “rules” or “lens” of science in comparison to their other subject areas (i.e., Math, Social Studies, and Language Arts). I chose to use students' other classes for comparison, to couch a philosophical discussion in a language they could understand. I wanted students to realize science as a distinct and defined (not better) enterprise, concerned only with understanding the natural world through observation, limited in the questions it can ask and answer. In considering an epistemic mosaic over a science-religion dichotomy or science-religion continuum (Scott, 2004), I hoped my students would feel more comfortable entering later conversations about human evolution.

I wanted my students to revisit the NOS for another reason; students use faulty views of the NOS (Table 3.5) to discredit evolutionary theory (Daguer & Boujaoude, 2005).

Table 3.5 <i>Students' Alternative Conceptions of NOS</i>	
Alternative conception	Reference
Evolution is based on little evidence or no proof.	Daugher & Baoujaoude, 1997; Sinatra, et al., 2003
Evolution is weak because it is just a theory and is not based on hard facts.	Daugher & Boujaoude, 2005; Nehm & Schonfeld, 2007
Evidence is trustworthy if it is obtained through direct observation only.	Daugher & Boujoude, 2005
Evolution cannot be verified through experimentation so the topic is outside of what science can do and know.	Daugher & Boujoude, 1997
Science can be used to answer all questions.	McComas, 1988
Science provides absolute proof.	Chiapetta & Koballa, 2004; McComas, 1998

Therefore, students needed a reminder of the essential nature of observation to scientific knowledge because, “sooner or later, the validity of scientific claims is settled by referring to observations of phenomena” (AAAS, 1990, p. 4), and a reminder of how observation fits within a larger context (observations form the basis of inference, hypothesis, theory, and explanation—which extend scientific knowledge) (Ziman, J., 1978; Chiapetta & Koballa, 2006). Increasing

NOS understandings might help students later see that what scientists know about human evolution is based on observation as well (observation of extinct skulls in our context) and the inferences, hypotheses, and theories derived from these skull observations.

Based on the argument proposed above, I decided to focus on three major NOS concepts in the NOS scaffolding unit: (a) science is empirically based, (b) science is concerned with the natural world, and (c) science is one (of many) way of knowing the world. Points (a) and (b) correspond to one of Lederman's identified nature of science concepts (2007): "scientific knowledge is... empirically based (based on and/or derived from observations of the natural world)" (p. 833), and on the NSS, Benchmarks, and GPS. Point (c) is not explicitly proposed in any of the standards, but does arise in recommendations in the science education literature (e.g., Anderson, 2007). I predicted that explicitly grappling with these three NOS concepts would help students later "manage" our ventures into the world of human evolution, as it sets parameters for how science is uniquely concerned with the natural versus supernatural world, and how what we know about human evolution is based on what we have observed. I developed four learning experiences aligned to the three major points listed above. And, I developed my own unique lessons rather than trying to make a "best fit" out of those presented in the literature (e.g., NAS, 1998; McComas, 1998, Evolution and the Nature of Science Institutes, (2011), Understanding Evolution, 2011).

Nature of science and "The Standards".

During most of the year between August and April, I relied on the Georgia Performance Standards (GPS) (2006) for curricular guidance. I relied on the state GPS over the county Academic Knowledge and Skills (AKS) and the NSS and Benchmarks due to a matter of ethics, administrative pressure, and standardized testing. In our state school system, students' promotion

to eighth grade depended on their performance on a high stakes standardized test administered in April. I felt ethically responsible to cover the GPS aligned to this assessment to properly and fairly prepare my students for this test. Moreover, my administration required our department to construct a common scope and sequence, and common nine weeks assessments in order to insure accountability to the standards and toward optimal student achievement. Freedom to develop thematic, creative pedagogical units was limited by the structure imposed by standardized testing and all the intermediate benchmarks to be met in the process. Last, my teacher evaluations (both informal drop-in observations by the administration, and bi-yearly formal write-ups) were based on student achievement on both nine week and standardized testing results. This accountability climate prioritized the coverage of the standards, leaving pedagogical design and theory up to teachers to creatively incorporate.

My research intervention occurred post standardized testing, changing the climate for teaching and learning. Instead of looking to the standards to drive instruction, I looked to the pedagogical concepts of backwards design (Wiggins & McTighe, 1998). Thinking in terms of backwards design couches pedagogy with the big ideas (i.e., How can we step into the shoes of paleoanthropologists in order to understand science and evolution?). The standards transform from a laundry lists of items to cover, to supplemental objectives thematically tied together. Instruction focuses on what the students should know and be able to do by the end of a unit couched in authentic practice and assessment. In the case of the scaffolding NOS unit, students should know that science is empirically based, focused on the natural world, and unique compared to other epistemologies. They should step in the shoes of a philosopher of science and be able to identify the questions science can and cannot answer and the “rules” or assumptions

that science makes—all in preparation for accommodating normative views of human evolution. In sum, I used my backwards design goal as an initial theoretical mesh, weaving in the standards later on in the preparation of this document to show alignment.

During curriculum development, I was most familiar with the GPS. End of course exams, standardized testing determining student promotion, and my own teacher evaluations aligned to the GPS. I was exposed to the NSS and Benchmarks as a graduate student at my University rather than through the experiences at my middle school. These exposures were brief and unapplied through readings and implicitly applied through summer staff development courses funded by Teacher Quality Grants. My understandings of the NSS and Benchmarks enhanced somewhat when I co-directed several of these workshops. I have not thoroughly examined and codified the NSS and Benchmarks for similarities and differences to the GPS until now in the explication of my curriculum. And I have thus made several revelations about “the standards” during this process:

- The GPS drove instruction prior to standardized testing; Backwards design drove instruction post standardized testing.
- I recognized that the standards (NSS, Benchmarks, and the GPS) provided various views of what 7th grade science students should know and be able to do. Because the standards differed in regards to specific objectives to be covered, the curriculum development process was more complicated and confusing. Backwards design (e.g., How can 7th grade students engage in the practice of paleoanthropology to develop normative views of NOS and human evolution?) provided a better tool for focused curricular development over the standards. So the curriculum came first, followed by alignment to the standards. During teaching and learning prior to standardized testing, I

tried to use backwards design as a framework for curriculum development, but I had to adhere more strictly to the GPS and our school's scope and sequence, which sometimes conflicted with the time necessary to implement backwards design effectively.

- NOS standards (NSS, Benchmarks, and the GPS) were summarized in bulleted paragraphs and contained multiple objectives (e.g., Scientists differ greatly in what phenomena they study and how they go about their work. Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence) (AAAS, 1993, p. 12). Lack of simple organization made it difficult to create a curriculum based on the standards. Lederman's (2007) concise list of NOS concepts based on evaluations of the NSS and Benchmarks provided more practical guide for identifying NOS learning objectives.
- Important objectives are missing from the standards such as comparing the NOS with other epistemologies.
- Comparing the NSS, Benchmarks, and GPS does not clarify the distinction between NOS and inquiry, and rather conflates them.
- The standards do not facilitate a distinction between the terms: observation, evidence, data, knowledge, and measurement. This leaves little guidance for teachers during curricular development.

I developed Table 3.6 to show the correlation between the curricular concepts to be addressed based on backwards design. Curricular concepts are then linked to particular standards or references. Only certain aspects of one standard may be aligned to a curricular concept. The

third column indicated how the standard was codified by the particular publication in terms of characteristics of science, NOS, inquiry, or a combination. Similar concepts overlap into inquiry, NOS, or characteristics of science categories, confusing the distinction between these theoretical categories.

Table 3.6 <i>NOS and the Standards</i>			
Three NOS concepts addressed		Standard and Reference	Categorized by reference as NOS and/or Inquiry
Science as empirically based		Scientific knowledge is...empirically based (based on and/or derived from observations of the natural world) (Lederman, 2007, p. 833).	NOS
		Students will investigate the characteristics of scientific knowledge and how that knowledge is achieved (S7CS8) (GPS, p. 5).	Characteristics of science NOS
		Scientific investigations usually involve collecting evidence, reasoning, devising hypotheses, and formulating explanations to make sense of collected evidence (GPS S7CS9.b., p. 5)	Characteristics of science NOS Inquiry
		Scientists differ greatly in what phenomena they study and how they go about their work. Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence (AAAS, 1993, p. 12).	NOS
		Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models (NRC, 1996, p. 171).	NOS
		Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables (NRC, 1996, p. 145).	Inquiry
		Students should base their explanation on what they observed (NRC, 1996, p. 145)	Inquiry
	and required to uphold up high standards of practice when making observations	Students will explore the importance of curiosity, honesty, openness, and skepticism in science and will exhibit these traits in their own efforts to understand how the world works. a. Understand the importance of—and keep—honest, clear, and accurate records in science (GPS S7CSI, p. 3).	Characteristics of Science Habits of Mind
		Accurate record keeping, data sharing, and replication of results are essential for maintaining an investigator's credibility with other scientists and society (GPS, S7CS9.e., p. 5).	Characteristics of Science NOS Inquiry

		Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables (NRC, 1996, p. 145).	Inquiry
Science as concerned with the natural world		Scientific knowledge is...empirically based (based on and/or derived from observations of the natural world) (Lederman, 2007, p. 833).	NOS
		Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models (NRC, 1996, p. 171).	NOS
		Identify questions that can be answered through scientific investigations (NRC, 1996, p. 145).	Inquiry
Science as one way of knowing		Anderson, 2007	NOS

Table 3.6 illustrates the messy nature of curricular development. Using the standards for developing thematic units based on big ideas becomes time consuming and confusing.

Backwards design, then becomes a more effective approach for curricular design. The downside of backwards design, includes covering all of the standards as a selection of particular standards aligns to curricular outcomes.

NOS learning experience one: Anticipation guide.

Essential question posted: How does science compare and contrast with other disciplines?

Approximate instructional contact time: 20 minutes

Learning experience choice and design.

Learning experience one (Figure 3.1) of the NOS scaffolding unit functioned as both a pedagogical and research tool, illustrating the fusion of teaching and learning, assessment, and research that occurs during teacher research. I dedicated the following section to discussing the development of Figure 3.1 as a pedagogical tool. Figure 3.1 as a research tool is discussed in the data collection section of this methods chapter.

As a pedagogical tool, the lesson served as an anticipation guide (Buehl, 2009).

Anticipation guides were developed by Bean and Peterson (1981) and have also been referred to

in the literature as anticipatory sets and reasoning guides. Anticipation guides ideally comprise of statements rather than questions to encourage abstract thinking, sense-making, questioning, prediction, and inference (Herber & Nelson, 1977). Effective for all content areas, these guides are administered pre and post instructional intervention as well as visited throughout instruction. Pre-instruction they are designed to: (a) introduce students into a new lesson, (b) prime students brains for learning, giving students a preview of what is to come and what is important to know (c) incite extrinsic motivation, (d) identify alternative conceptions and (e) provoke disagreement or challenge belief. During instruction, these guides provide a framework for discussion, sense-making, intellectual engagement and student monitoring of personal learning. Post-instruction, they mark student conceptual development (Buehl, 2009; Kozen, Herber & Nelson, 1977; Murray, & Windel, 2006; Wood & Mateja, 1983). Finally, anticipation guides as sense-making and intellectual engagement strategies are consistent with current learning theory supported by extensive research (Banilower, et al., 2008; NRC, 2003).

NOS learning experience two: Comparing science with football.

Essential question posted: How does science compare and contrast to other enterprises?

Approximate instructional contact time: 70 minutes

Lesson experience choice and design.

In this lesson, students compared the enterprise of science to the game of football in order to think about science as unique, and with its own set of defining “rules”. These rules determine what questions science can answer, the criteria for collecting data/making observations, the consequences for doing “bad” science, and the healthy doses of skepticism, self-examination, and cross-examination that occur as a checks and balances system to maintain higher standards of practice. Such discussion was consistent with the two major pedagogical emphases identified

in the NOS pre/post-test: a) science as a unique enterprise, and b) scientific knowledge based on observation.

What is the Nature of Science?	
1. Science knowledge is based on beliefs. The definition of belief is below. —noun	
1. something believed; an opinion or conviction: <i>a belief that the earth is flat.</i>	
2. confidence in the truth or existence of something not immediately susceptible to rigorous proof: <i>a statement unworthy of belief.</i>	
3. confidence; faith; trust: <i>a child's belief in his parents.</i>	
4. a religious tenet or tenets; religious creed or faith: <i>the Christian belief.</i>	
a. 100% true b. sort of true c. I don't know d. sort of false e. 100 % false	
Explain your answer:	
If you did not choose answer choice a, then how would you make the statement 100% true?	
2. Science knowledge is formed only through observation.	
b. 100% true b. sort of true c. I don't know d. sort of false e. 100 % false	
Explain your answer:	
If you did not choose answer choice a, then how would you make the statement 100% true?	
3. Science can answer all questions.	
a. 100% true b. sort of true c. I don't know d. sort of false e. 100 % false	
Explain your answer:	
If you did not choose answer choice a, then how would you make the statement 100% true?	
4. Data collected in science are collected with honesty, clarity, and accuracy.	
a. 100% true b. sort of true c. I don't know d. sort of false e. 100 % false	
Explain your answer:	
If you did not choose answer choice a, then how would you make the statement 100% true?	
5. Science must follow certain rules.	
a. 100% true b. sort of true c. I don't know d. sort of false e. 100 % false	
Explain your answer:	
If you did not choose answer choice a, then how would you make the statement 100% true?	

Figure 3.1. NOS Pre/Post Anticipation Guide. More space for writing short answer responses was provided on the actual questionnaire.

I chose football as a reference for comparison because most of my students were familiar with the game, either through playing the sport, cheerleading, or spectating. I based this decision also on constructivist learning theory; learning does not occur in a vacuum, but interfaces with one's prior conceptual framework. I also borrowed from research on "progressive formalization" in which students build on informal concepts they bring into classrooms (such as football), to construct more formal ideas such as the nature of science (NRC, 2003, p. 137). I chose to use the term "rules", keeping in mind the developmental level of my students and the terms that they use in their everyday worlds and in agreement with the language used in the game of football. I did not use the word "guidelines" as this term insinuates that scientists loosely adhere to the "rules" listed above. I chose not to use the word "standards" as this term is not associated with the language used in the game of football. Overall, I wanted students to see that the "rules" of science, are just as unique, integral, and unwavering to science as the "rules" are to football. Also, I wanted to emphasize that science is no "better" than any other enterprise, just different in its overall mission and the "rules" that frame it, just as football is no "better" than tennis or swimming. Again, such an approach might help students discard a dichotomous view of science and religion, and understand the parameters set by science.

Students were given individual handouts with a graphic organizer to compare and contrast science with football, noting similarities but also differences on six domains (Figure 3.2). Research (Griffin & Malone, 1995; Robinson & Kiewra, 1995) has suggested that graphic organizers assist students with recognizing relationships, which in turn facilitate subsequent application and transfer of conceptual understandings. Students were given approximately ten minutes to fill in the graphic organizer on their own. Time for thinking on one's own provided

students with time for sense-making, one of Smith and Siegel's (2004) criteria for understanding. Then, students were encouraged to collaborate for five minutes with their neighbor or "elbow partner" to add additional ideas to their graphic organizer. Research has suggested that such collaboration can increase achievement (Good, Mulryan, & McCaslin) motivation, and engagement (Ryan, 2001). Last, I led a whole group discussion of the activity using the overhead projector to assimilate all classroom ideas into one whole-class graphic organizer—a duplicate to the one completed individually and with partners, but completed with ideas from various student input and the input of the teacher to clarify misconceptions/enhance responses. Figure 3.3 shows the final class product of the activity.

NOS learning experience three: Which lens is best?

Essential question posted: What questions can science answer?

Approximate instructional contact time: 15 minutes

Learning experience choice and design.

The purpose of this learning experience was to challenge learners to think about different ways of knowing (epistemologies), and to consider an epistemic mosaic rather than a science-religion dichotomy. This lesson was another attempt to help students "find a place to stand between two extremes" (Scharmann, 1990, p. 98) and formalize the parameters of science—scaffolding measures to prepare students for future conversations about human evolution.

This lesson experience was facilitated through direct instruction and lasted approximately ten to fifteen minutes. I collected five different pairs of glasses (three are shown in Figure 4), each representing a different enterprise or "lens" in which to interpret the world: a) lab safety glasses represented science, b) psychedelic purple glasses with orange lenses represented social

studies, c) blood shoot, blue-pupiled glasses represented math, d) sunglasses represented language arts, and e) regular prescription glasses represented religion/spirituality.

Comparing and Contrasting Science with Football			
Parameter	Science Only	Both	Football Only
What is the ultimate goal?			
Who is involved?			
What are the rules?			
Who makes sure the rules are enforced?			
What happens if you break a rule?			
Who is watching?			

Figure 3.2. Graphic Organizer Comparing Science and Football. Students filled out the organizer individually, and then modified their responses via small group and whole group class discussion.

Parameter	Science Only	Both	Football Only
What is the ultimate goal?	Science seeks to answer questions dealing with the natural world.	To be successful and achieve the goal.	To get points by getting field goals and touchdowns. To win the game.
Who is involved?	Anyone can do science if they can make observations.	People are involved.	Anyone can play if they can hit, run, throw, catch, tackle, etc.
What are the rules?	1. Collect valid data. 2. Make accurate, honest, and clear observations. 3. Experiments must be conducted multiple times. 4. Refrain from putting your beliefs or opinions into the data. 5. Control variables 6. Science knowledge can change.	Wear safety gear Not following the rules may have consequences	1. No grabbing facemask. 2. No holding on offense. 3. No off sides. 4. No pass interference. 5. No roughing the passer or kicker. 6. Stay in bounds.
Who makes sure the rules are enforced?	Bosses, other scientists	Teachers and mentors help to enforce the rules. People with authority enforce the rules.	Refs, coaches
What happens if you break a rule?	1. Invalid data 2. Fired 3. Demoted 4. Lower grade 5. Lose respect	You will get demoted or penalized	1. Get kicked off the team 2. Penalties 3. Get benched 4. Get suspended 5. Fined 6. Lose yardage

Figure 3.3. Completed Graphic Organizer Comparing Science and Football. This was after a sequence of individual work, small group discussion, and then whole class discussion.

Glasses were chosen based on accessibility (e.g., I was already wearing a prescription pair of glasses and had a pair of sunglasses in my purse). I did not use the term “epistemology” in this discussion. I wanted students to engage in the philosophical discussion, without being distracted by esoteric language. Moreover, I chose “lenses” based on students’ daily experiences in their other core classes, rather than chose enterprises such as advertising, philosophy, theology, biochemistry, etc., which students may or may not be familiar with.



Figure 3.4. Epistemological Glasses. Glasses representing various interpretive lenses are shown. They were used via demonstration to challenge learners to think about all the different ways of knowing, and to consider an epistemic mosaic rather than a science-religion dichotomy.

I began this lesson experience by putting on the “math” pair of glasses, and then asking the students how one would interpret the world through such a lens. Taking responses from various students and through Socratic questioning (Paul & Elder, 2006), we decided that the “lens” of math “sees” the world mostly through numbers. I donned each pair of glasses one by one, and we discussed how social studies “sees” the world through culture, economics, and history; language arts “sees” the world through language, story-telling, metaphor, and simile; science sees the world through observation of natural phenomenon; finally, religion “sees” the world through teachings from religious leaders, faith, conviction, and supernatural inspiration. I emphasized that each enterprise views the world in different ways and creates understandings in different ways. Thus, no one discipline is necessarily better than the other. They are different,

each outlined by a certain set of rules. All are unique, but all can be important in helping to create a holistic and rich life experience.

NOS learning experience four: To be or not to be science.

Essential question posted: What are the characteristics of science?

Approximate instructional contact time: 30 minutes

Learning experience choice and design.

This learning experience challenged students to differentiate between characteristics and non-characteristics of science. It revisited concepts explored in the NOS lesson experiences two and three; however it was more student-centered in comparison. Thus, the NOS lesson experiences gradually worked toward student independence in thinking about NOS concepts.

Pairs of students received a stack of small cards with words or phrases (Figure 3.5). Pairs collaborated to sort the cards onto two separate plastic cups, one labeled “science” and one labeled “not science” (Figure 3.6). The card sort served as a graphic organizer for students, making concepts more visible and accessible for discerning relationships/non-relationships. As mentioned in NOS lesson one, research (Griffin & Malone, 1995; Robinson & Kiewra, 1995) has suggested that graphic organizers facilitate conceptualization of relational patterns, which in turn can lead to greater application and transfer of conceptual understanding. Students worked in pairs to capitalize on the cognitive (i.e., justifying and gaining exposure to ideas) and affective (i.e., increased motivation and engagement) benefits of collaboration (Ryan, 2001). Last, whole-class discussion that I facilitated transpired to allow pairs of students to share their categorization of cards, and further capitalize on the benefits of collaboration before mentioned.

Extant Skulls Learning Experiences

Rationale.

The extant mammalian skulls learning experiences served as another frontloading unit prior to the unit on human evolution. Like the NOS unit before it, the purpose of the extant skull learning experiences was to a) create a framework of scientific vocabulary, theory, and experience for future inquiries into our human past. The rationale behind exploring extant skulls prior to human evolution is explored below. First, I established how mammalian skulls were relevant to students, as required by constructivist learning theory. Second, I discussed the importance of a working knowledge of mammalian comparative anatomy prior to conducting extinct hominin comparative anatomy to motivate, situate, and scaffold the learning process, as well as hone NOS concepts important to helping students later find “a place to stand”. Last, I related the teaching and learning of extant mammalian skulls to science education standards. This rationale section served as a segue to explaining the details of each extant mammalian skull learning experiences.

Prior knowledge of and experience with extant mammalian skulls.

My students had conceptual hooks for assimilating new conceptions regarding extant mammalian skulls. These conceptual hooks were likely conceived from identifiable experiences in our 7th grade classroom as well as more varied elementary school and cultural experiences. Students’ prior knowledge of skulls and mammals had important implications for later inquiries into human evolution based on social constructivist and conceptual change theory (Dole & Sinatra, 1998). Here, I discussed student prior knowledge and experiences with skulls, followed by a similar discussion on the topic of mammals.

Can answer any question	Can only answer certain questions
Is based on beliefs	Is based on observation
Does not adhere to any certain set of rules	Adheres to a certain set of rules
Seeks to understand the meaning of life	Seeks to understand the natural world
Can only be conducted by trained scientists	Can be conducted by anyone who can make observations
Does not rely on ethical behavior	Is based on data that is collected with honesty, clarity, and accuracy
Is based on data that is collected through one experimental trial	Is based on data that is collected through many experimental trials
Is not subject to scrutiny	Is subject to scrutiny
Cannot change	Can change
Can answer religious questions	Can answer questions that can be answered through observation/experimentation
Can measure God	Can measure phenomena of the natural world
Is not limited	Is limited
Is no different from other disciplines like social studies or language arts	Is unique
Is established by scientists working alone	Is established by scientists working together
Faith	Ruler, graduated cylinder, microscope, telescope

Figure 3.5. NOS card Sort. These terms and phrases were cut out and sorted by students into cup labeled “science” or “not science”.



Figure 3.6. Student Photo of NOS Card Sort. A pair of students sorts cards into “science” and “non-science” cups.

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My students had conceptual hooks for assimilating new conceptions regarding extant mammalian skulls. These conceptual hooks were likely conceived from identifiable experiences in our 7th grade classroom as well as more varied elementary school and cultural experiences. Students' prior knowledge of skulls and mammals had important implications for later inquiries into human evolution based on social constructivist and conceptual change theory (Dole & Sinatra, 1998). Here, I discussed student prior knowledge and experiences with skulls, followed by a similar discussion on the topic of mammals.

My students indirectly encountered skulls in my classroom through explorations of cellular organization and vertebrate dissections. My students learned about cellular organization during the third month of their 7th grade year with me. Students created personalized "Baby Books" to relate genetics concepts to their own development. One portion of this project had students create sequential drawings of their embryonic development from a single, fertilized cell to a complex multi-cellular individual. For example, we covered the idea of bone cells assimilating to create bone tissue, bone tissue assimilating to create bone (like our skull), and bones assimilating to create the skeletal system for anatomical structure and support. During the second semester of the year, we dissected frogs and sharks, comparing and contrasting the organ systems, and exploring the skeletal system in frogs. Moreover, it was possible that students encountered the skeletal system (and therefore skull) lessons in elementary school. However, this assumption could not be verified; covering the human body and skeletal system was not a state

or county standard in elementary schools at the time of this study. Factors outside of the school setting (e.g., Halloween and forensic T.V. shows) likely impacted my students' notions of skulls.

Inquiries regarding mammals were present in our classroom, yet less direct. One of our curriculum units explored the classification of living organisms, and students were required to create a poster showing the classification levels of a chosen vertebrate (most chose a mammal to classify and present). Mammals also permeated our discussions during our ecology unit, and infused topics dealing with food chains, food webs, feeding roles, competition, and symbiotic relationships. Earlier educational experiences for my students also involved mammals (e.g., beginning in our state's kindergarten program, students identify the similarities and differences between animals, and match pictures between parents and offspring) (GPS, 2006). Last, mammals were ubiquitous in the life of my students on a cultural level; mammals were pets, local wildlife, centerpieces of television and movies, etc.

In sum, my students brought prior conceptions of skulls and mammals to our learning environment during this study. This prior knowledge served as a motivational tool given its personal relevance and as a framework for constructing more complex scientific vocabulary, skills, and theory.

Learning about extant mammalian skulls prior to learning about human evolution.

My students and I studied extant mammalian skulls prior to studying extinct hominin skulls for multiple reasons: a) to make learning relevant (as explained above), b) as a motivational catalyst, c) to situate our learning as paleoanthropologists, d) as a scaffolding technique, and e) to develop the crucial and foundational skills of observation and inference, and f) to explicitly grapple with important NOS concepts to help students find “a place to stand”.

First, I used twelve (Table 3.7) mammalian skull casts to motivate students. My students from previous years thought the skulls were “really interesting” and “cool” (Beall, 2007); the skulls are novel, morbid, and linked to the myriad forensics T.V. shows kids find interesting. Also, “touch matters” in enhancing learning (Jones, Minogue, Tretter, Negishi, & Taylor, 2006), and the tactile nature of the skulls pulls students into discovery learning. One of my students prior to this study shared that she enjoyed “being able to actually have skulls to look at and observe and touch and feel” (Beall, 2007). So, the skulls tapped into the affective domain of learning as suggested by many who study evolution education (e.g., Anderson, 2007; Dole & Sinatra, 1998; Sinatra, Brem & Evans, 2008).

Table 3.7 <i>Extant Mammalian Skulls Used in Learning Experiences</i>		
Scientific Name	Common Name	Feeding Role
<i>Homo sapiens</i>	Human (male and female)	Omnivore
<i>Pan troglodytes</i>	Chimpanzee	Omnivore
<i>Pongo pygmaeus</i>	Orangutan	Frugivore
<i>Gorilla gorilla</i>	Gorilla (male and female)	Herbivore
<i>Puma concolor</i>	Mountain Lion	Carnivore
<i>Felis domesticus</i>	Domestic Cat	Carnivore
<i>Canis lupus familiaris</i>	Dog (Great Dane)	Carnivore
<i>Canis latrans</i>	Coyote	Carnivore
<i>Odocoileus virginianus</i>	White-tailed deer	Herbivore
<i>Equus caballus</i>	Horse	Herbivore
<i>Bos primigenius</i>	Cow	Herbivore
<i>Ursus americanus</i>	Black Bear	Omnivore
<i>Alligator mississippiensis</i>	American Alligator (reptilian outlier)	Carnivore

Studying extant mammalian skulls situated our learning in paleoanthropology. In paleoanthropology the observation, inference, and comparative anatomy of mammalian skulls is a pre- and co-requisite for studying extinct hominin skulls. Paleoanthropologists apply their expert knowledge of mammalian comparative anatomy to reconstruct the details of our hominin past; knowns become reference points for unknowns (Freeman & Herron, 1997). For example, what paleoanthropologists know about mammalian teeth and related diets becomes a reference

point for observing extinct hominin teeth and inferring their diets. Paleoanthropologists know that large incisors in extant primates indicate a diet high in fruits. Direct observation provides evidence for such claim. The indirect observation of large incisors on an extinct hominin skull would produce the same inference; a diet high in fruit. Like paleoanthropologists, my students and I first explored the known world of extant mammalian skulls. We honed our skills of making observations and inferences and built a working knowledge and vocabulary of extant mammalian skull characters (i.e., dental formula, mandibular molar size, sagittal crest, brow ridge, eye position, foramen magnum, brain case size, and prognathism). The learning experiences dedicated to these processes served as a scaffold for future observations and inferences of hominin skulls.

Exploring mammalian skulls created rich opportunities for observation and inference—crucial and foundational skills of science (Lederman, 2007). In *Nature of Science: Past, Present, and Future*, Lederman explained that “First students should understand the crucial distinction between observation and inference” in developing normative views of NOS. He defined observations and inferences:

Observations are descriptive statements about natural phenomena that are ‘directly’ accessible to the senses (or extensions of the senses) and about which several observers can reach consensus with relative ease (e.g., descriptions of the morphology of the remnants of a once living organism). Inferences, on the other hand, go beyond the senses. For example, one may develop explanations about the observed morphology in terms of its possible contributions to function” (p. 833).

My students made observations and inferences of extant mammalian skulls, and we explicitly discussed and practiced how to do so. Presenting their observations and inferences to their peers

also served as an authentic assessment in the study. Making observations and inferences of extant mammalian skulls built a knowledge and skill base important for making observations and inferences of extinct hominin skulls. I also used these learning experiences to reemphasize the relationship of observation and how we come to know in science. This became important later; what we know about our human past is also based on observation—a notion in contrast to student alternative conceptions of evolution as “just a theory” (Daugher & Boujoude, 2005; Nehm & Schonfeld, 2007).

Extant skulls and the standards.

There were no county, state, or national science standards for teaching about extant skulls. However, I used extant skulls as a contextualized vehicle to continue the conceptual strands initiated in the NOS scaffolding unit, to actualize inquiry-based content standards, and to introduce new content-oriented strands to extend into the hominin skull learning experiences.

My students grappled with the same NOS concepts as they had done in the NOS scaffolding unit, but now in the contextualized environment of comparative mammalian anatomy. This technique provided further scaffolding toward cognitive clarity. In observing the extant skulls, I challenged students see science as empirically based (AAAS, 1993; GPS, 2006; Lederman, 2007; NRC, 1996 & 2000), and dependent on honest, clear, and accurate observations (Lederman, 2007; NRC, 1996; GPS, 2006). Students were also challenged engage in the essential features of inquiry: “Learner engages in scientifically oriented questions...Learner gives priority to evidence...Learner formulates explanations from evidence...[and] Learner communicates and justifies explanations (NRC, 2000, p. 29). Addressing these essential features of inquiry in the extant skull learning was a scaffolding technique to later address the notion that

inferences about our hominin past are also linked to observation; they are not unfounded, whimsical ideas, and the same rules applied to interpreting the extant world apply to the extinct world as well.

Additional content standards dealing with the skeletal system, feeding roles, and diversity of living things were also infused in the extant skull learning experiences. We reviewed the purpose and function of the skeletal system (focusing on the skull), learned how to construct dental formulae, identified and interpreted skull characters, and revisited feeding roles discussed earlier in the year during our ecology unit, yet now in relation to dentition. More important for scaffolding future inquiries, we explored the similarities between mammalian skulls in inferring relatedness and common descent. The content-oriented standards addressed in the extant mammalian skulls unit were organized in Table 3.8 below.

Table 3.8 <i>Content-oriented Standards and the Extant Skull Learning Experiences</i>	
Content Addressed	Standard and Reference
Skeletal System	“Students will explain that cells are organized into tissues, tissues into organs, organs into systems, and systems into organisms” (GPS).
	“Students will explain the overall purpose of major organ systems in the human body (i.e. digestion, respiration, reproduction, circulation, excretion, movement, control, and coordination, and for protection from disease)” (GPS).
	Students will understand that “The human organism has systems for digestion, respiration, reproduction, circulation, excretion, movement, control and coordination, and for protection from disease. These systems interact with one another (NRC, p. 156).
	“Students should know that like other animals, human beings have body systems for obtaining and providing energy, defense, reproduction, and the coordination of body functions (AAAS, p. 129).
Feeding Roles/Relationships	“Students will demonstrate in a food web that matter is transferred from one organism to another and can recycle between organisms and their environments” (GPS).
	Students will understand that “Populations of organisms can be categorized by the function they serve in an ecosystem...” (NRC, p. 157).
	“Students should know that animals and plants have a great variety of body plans and internal structures that contribute to their being able to find food and reproduce (AAAS, p. 104).
	“Students should know that two types of organisms may interact with one another in several ways: They may be in a producer/consumer, predator/prey, or parasite/host relationship...” (AAAS, p. 117).
Diversity of Living Things	Students will “investigate the diversity of living organisms and how they can be compared scientifically (demonstrate the process for the development of a dichotomous key)” (GPS).
	Students will understand that “Millions of species of animals, plants and microorganisms are alive today. Although different species might look dissimilar, the unity among organisms becomes apparent from an analysis of internal structures, the similarity of their chemical processes, and the evidence of common ancestry” (NRC, p. 158).
	“Students should know that similarities among organisms are found in internal anatomical features, which can be used to infer the degree of relatedness among organisms. In classifying organisms, biologists consider details of internal and external structures to be more important than behavior or general appearance (AAAS, p. 104).

Extant skulls learning experience one: The human skull

Essential question posted: What can we learn from our own skull?

Approximate instructional contact time: 55 minutes

Learning experience choice and design.

This lesson experience introduced the extant mammalian skulls learning experiences. It tapped into students' prior knowledge, made relevant connections to students' lives, and introduced new concepts for future application. Overall during this lesson experience, students learned about their own skull and dentition. They learned that observing teeth can be used to construct a dental formula and infer diet.

This lesson was scaffolded by a graphic-organizer handout (Figure 3.7), and included direct instruction and cooperative learning during dental observations and data collection. The lesson experience began with tapping into students' prior knowledge. Students shared their understandings of the functions of bones (skeletal system) and the functions of the skull. I wrote the assimilation of their comments on an overhead display of the handout. Next, students worked collaboratively. They observed and counted their neighbor's teeth. We completed a data chart compiling the numbers of teeth versus the number of students in the classroom; we noted the variation that exists among individuals and numbers of teeth (for example, one of my classes had a range of 22 to 32 teeth). The students also shared their observations of teeth, noting differences in shapes in sizes. We filled out another chart, giving formal names to the different types of teeth (i.e., incisors, canines, premolars, and molars) and their functions (i.e., cutting, tearing, and grinding). Through direct instruction, I showed students how to create a dental formula of their teeth.

A formal quiz (Figure 3.8) serving as a formative assessment was administered the following day to assess students' recall of the concepts covered during the lesson experience, What can we learn from our own skull? This quiz did assess understanding, as it did not meet the criteria established by Smith and Siegel (2004); understanding is established by demonstrating “connectedness, sense-making, application, and justification” (p. 563). However, Wiggins and McTighe (1998) have suggested that assessments “assess breadth independently of depth” (p. 88), signifying the appropriateness of assessing for detail as well as the big ideas.

WHAT CAN WE LEARN FROM OUR OWN SKULL? HANDOUT 1A

Name: _____ What Can We Learn From Our Own Skull?

Part One:

A. What are the functions of bones in the skeletal system?

- _____
- _____
- _____
- _____

B. What are the functions of the bones in your skull?

- _____
- _____
- _____
- _____

Part Two:

A. Observe a friend's teeth.

- How many teeth does your friend have? _____
- How many teeth do you have? _____
- Describe your friend's teeth. How are they different from one another?

B. Fill in the chart below to show the number of students compared to the number of total teeth.

Number of Teeth	Number of Students

WHAT CAN WE LEARN FROM OUR OWN SKULL? HANDOUT 1B

C. List the four different types of teeth and the function of each.

Type of Tooth and Abbreviation	Teeth Function

D. Use the image of the adult human below and label the teeth. Then, work with your teacher to define and construct a dental formula for the image, a dental formula for you, and a dental formula for your friend (partner).




Individual	Dental Formula
Image on this page	
You	
Your friend	

Figure 3.7. Graphic Organizer of Human Skull Learning Experience. Concepts relayed included the function of bones and the skull, the types and functions of teeth, and how to construct a dental formula.

WHAT CAN WE LEARN FROM OUR OWN SKULL?: ASSESSMENT

Name: _____

A. List three functions of the skeletal system.

1. _____
2. _____
3. _____

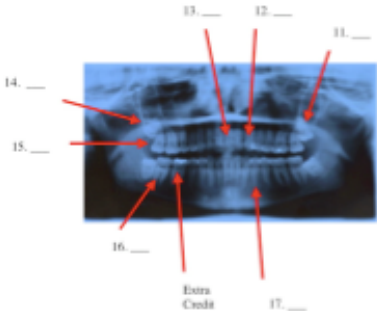
B. List three functions of the skull.

4. _____
5. _____
6. _____

C. Complete the matching section below to show your understanding of the different types of teeth.

Type of Tooth and Abbreviation	Tooth Function
7. Incisor (I) _____	A. These teeth are used for grinding and are permanent teeth.
8. Canine (C) _____	B. These teeth are for cutting.
9. Pre-Molar (PM) _____	C. These teeth are used for grinding. They are deciduous, meaning they are lost and replaced by permanent teeth.
10. Molar (M) _____	D. These teeth are for piercing and tearing.

D. The image below is an x-ray of an adult human's dentition. Label the teeth as directed.



Extra Credit:
Look at the tooth indicated by "Extra Credit". Notice that the crown of the tooth is more white than the rest of the tooth. Why? Answer this on the back of your paper.

Figure 3.8. Human Skull Quiz. A formative assessment of lesson experience one (What can we learn from our own skull?) of the extant mammalian skulls lessons.

Extant skulls learning experience two: The gorilla skull

Essential question posted: What can we learn from gorilla skulls?

Approximate instructional contact time: 35 minutes

Learning experience choice and design.

This learning experience carried over concepts from learning experience one, What can we learn from our own skull?, while adding new explorations into skull characters, comparative anatomy, and the inferences that arise during such inquiries. Moreover, I wanted students to realize that skull characters give clues into the life of an organism; they can be used to reconstruct the life history of an organism. For example:

- The number and types of teeth can tell us if the animal was an herbivore, omnivore, or carnivore.
- The number of teeth can tell us the age of the individual. For example, a human skull with twenty or less teeth is likely a child.
- The size of the mandibular molar may suggest the type of vegetation consumed. Larger molars may suggest the animal subsisted on a coarse diet of nuts, whereas smaller molars may suggest a diet of soft vegetation.
- The teeth may suggest certain behaviors; gorillas are herbivores but have large canines used for defense and to show prowess.
- A large sagittal crest suggests a large surface area for muscle attachment and hence a strong bite (such as for the mountain lion) or may also be used to show dominance and prowess as in gorillas. Silverbacks stand quadrupedally, and turn their head to the side to display the crest as if flexing muscles to an opposing silverback.
- Forward facing eye sockets are signs of a predator who must hone in on and chase down prey, whereas eye sockets on the side are signs of a herbivore who must watch the periphery for predators. A cute saying is “eyes on the side, run and hide; eyes in the front, time to hunt”.
- The location of the foramen magnum (hole at the bottom of the skull where the spinal cord exits) can reveal whether the organism was a biped or quadruped. If the foramen magnum is directly under the skull so that the spinal cord exits perpendicular to the skull, then the animal is a biped. If the foramen magnum is off of center, the animal is quadrupedal.
- The pronounciation of the brow ridge in hominids can help the observer determine the gender of the organism (males have a more pronounced brow ridge).

Such logic would be reapplied during future learning experiences centered on reconstructing the life histories of other extant mammals and extinct hominins. Last, this learning experience was designed to revisit one of the important NOS concepts (science as empirical) as established in the NOS scaffolding unit. My students and I had explicit conversation about how to make observations of the gorilla skull (i.e., use the five senses, focus on facts that can be agreed upon) during this activity, and reviewed the idea that scientific knowledge is based on observation.

I used two 3-D Western Lowland gorilla skulls (*Gorilla gorilla gorilla*) as centerpieces of inquiry. One skull was female and one was male, important for observing skull differences in genders. I chose to use gorilla skulls to tap into student relevance and motivation; we completed a NOS unit at the beginning of the year dealing with the work of Dian Fossey and mountain gorillas, and we took a fieldtrip to the zoo to observe gorilla behavior in captivity. Thus, a former framework existed for accommodating new knowledge.

Students filled in a graphic organizer (Figure 3.9) listing novel skull characters to be identified, and providing space for students to respond in describing these characters and developing logical inferences explaining their purpose/function. A blend of direct instruction, Socratic questioning, and discussion transpired to facilitate the completion of the student handouts. I facilitated discussion, moving through the handout one skull character at a time, referring to the gorilla skulls on hand, taking comments from students, and writing down their ideas on a transparency of the handout displayed on the overhead. As a formative assessment/student reflection activity/summarizing activity, students wrote down their response to, “What is the difference between an observation and an inference” on a slip of paper to be handed in to me upon leaving class.

WHAT CAN WE LEARN FROM GORILLA SKULLS?: HANDOUT

Name: _____



Skull Feature	Observation of Gorilla Skull	Inference
Dental Formula		
Mandibular Molar Size		
Sagittal Crest		
Brow Ridge		
Eye Position		
Sexual Dimorphism		
Location of Foramen Magnum		
Brain Case Size		
Others: _____		

Figure 3.9. Graphic Organizer for Observing Gorilla Skulls.

Extant skulls learning experience three: Extant mammalian skulls

Essential question posted: What can we learn from an extant mammalian skull?

Approximate instructional contact time: 110 minutes

Learning experience choice and design.

The framework of vocabulary and inquiry skills refined during the first two learning experiences were applied in a more student directed sense in lesson experience three. Students worked in pairs (representative of the collaborative nature of science) and chose one 3-D extant skull (Table 3.7) to draw, observe, and generate logical inferences. They were instructed to title their drawing with both the common and scientific name of their extant mammal, label the teeth,

include the dental formula, and generate three questions for future inquiry. I led explicit discussion to remind students that drawing is another form of observation; their drawings should be accurate, clear, detailed, and specific for this reason; such direction revisited item four (Data collected in science re collected with honesty, clarity, and accuracy) from the NOS questionnaire. Last, the students were instructed to complete a graphic organizer (Figure 3.10), recording the observations of their skull, and related inferences. Students completed their own drawings and charts, but worked together in regards to generating observations and inferences prior to being recorded (Figure 3.10). Students were also informed that they would be presenting their skull to the class the following day; they would be challenged to tell the important story of their skull.

As an “exit slip” for the day, and also a formative assessment/reflection piece/summarizing activity, students wrote down their definition of observation, and gave an example of an observation and inference regarding their extant mammalian skull.

Extant skulls learning experience four: Extant skull presentations

Essential question posted: What can we learn from each other about extant mammalian skulls?

Approximate instructional contact time: 110 minutes

Learning experience choice and design.

This learning experience served as a culminating, authentic, performance task. Students were challenged to present their extant mammalian skull findings to their peers at a mock scientific symposium. Consistent with actual scientific symposia, presenters justified claims and engaged in discourse during peer review.

Skull Feature	Observation of Skull	Inference
Dental Formula		
Mandibular Molar Size		
Sagittal Crest		
Brow Ridge		
Eye Position		
Sexual Dimorphism		
Location of Foramen Magnum		
Brain Case Size		
Prognathism		
Other		
Other		


 A photograph showing two female students sitting at a table, focused on their work. The student on the left is writing on a large sheet of paper with a purple pen. The student on the right is also writing on a similar sheet. They appear to be in a classroom or lab setting, with other students and equipment visible in the background.

Figure 3.10. Students Observing an Extant Mammalian Skull. Students worked collaboratively to record observations and inferences on a graphic organizer (left of image).

Several events occurred prior to the presentations. Students were reminded to refer to their data collection charts (Figure 3.10) to present their skull. I told students to use the terms “observation” and “inference” in their presentations rather than less scientific terminology such as “I believe”. I also reminded students to use other skulls as references for making comparisons.

Each team of students divided the observations and inferences listed on their data charts from learning experience three, presenting that portion of data. One presenter could not hide behind the other. Student groups were given ten minutes to practice their presentation before the symposium commenced. The sequence of presentations was determined by willing volunteers.

Students also participated while in the audience—in order to promote a similar climate of actual scientific symposia. Students were instructed to hold any comments or questions until after each presentation. They were instructed to record any findings they considered interesting, or any questions that arose during the presentations. Last, they were informed of the question and answer session to transpire post-presentation; their questions/comments should be respectful and

constructive if contrary to presenter ideas. Such dialogue and interaction during assessment was encouraged because “a spontaneous question-and-answer session after a speaker’s polished presentation often reveals more about that person’s understanding than the talk itself” (Wiggins & McTighe, 1998, p. 86). I also used the time between presentations for “teachable moments”, to help students make connections to prior knowledge or introduce new ideas.

Complimentary to the performance task, this learning experience served as a formative and summative assessment, and as a scaffolding activity. The performance assessment provided a formal grade for summative purposes, but also provided formative feedback to both teacher and students, to identify weakness and strengths for future curricular modification. Last, the presentation experience served as a scaffold for future presentations of extinct hominin skulls.

Hominid Fossil Skull Learning Experiences

Rationale.

Teaching human evolution.

A rationale for teaching human evolution was discussed in the literature review. The major supportive points for the teaching and learning of human evolution are reiterated below:

- a) The topic of human evolution aligns with constructivist learning theory. The topic is relevant to students’ lives;
- b) The topic of human evolution is conducive to addressing major alternative conceptions (i.e., humans came from monkeys; evolution is *just* a theory; the human fossil record is relatively incomplete/weak) that are often obstacles for students to gain normative views of evolution;
- d) The hominin fossil record is diverse and extensive, conducive for discussing macroevolution and creating phylogenies;

e) The topic of human evolution situates learning within the discipline of paleoanthropology, creating a contextualized environment for inquiry, grappling with the NOS, and enhancing understandings of evolutionary theory.

Although not mentioned in the literature review, I perceived the topic of human evolution as a vehicle for teaching broader evolutionary concepts outlined in state and national teaching and learning standards. A study of human evolution could relay the broader evolutionary concepts of species changing over time (GPS, 2006), fossils providing evidence for evolution (GPS, 2006), observations of internal structures suggesting common ancestry (NSES, 1996), and extinction taking a common place in the history of life forms on our planet.

Teaching human evolution with 3-D extinct hominid skull replicas.

A more extensive rationale for teaching human evolution and major evolutionary concepts through the use of 3-D extinct hominid skulls was discussed in the literature. In summary, educators (Gipps, 1991 & 2005; Desilva, 2004; ENSI, 1999a, 1999b, & 1999c; Nickels, 1987; Robertson, 2007; Thomson & Beall, 2008) claimed that the use of 3-D extinct hominid skulls:

- Increased student understandings of evolutionary theory;
- Increased student understandings of NOS;
- Increased student acceptance of evolutionary theory;
- Increased students abilities to engage in comparative anatomy;
- Increased student abilities to do inquiry;
- Addressed student misconceptions of evolutionary theory; and
- Created a contextualized environment for learning

The hominid skulls used in the hominin skull learning experiences in this study are shown in Table 3.9.

Table 3.9 <i>Hominid Skulls Used in the Hominin skull learning experiences</i>	
Scientific Name	Age
<i>Homo sapiens</i>	Extant
<i>Pan troglodytes</i>	Extant
<i>Pongo pygmaeus</i>	Extant
<i>Gorilla gorilla</i>	Extant
<i>Homo floresiensis</i>	18,000 ya
<i>Homo neanderthalensis</i>	50-30,000 ya
<i>Homo erectus</i>	1.5 ma-200,000 ya
<i>Homo ergaster</i>	1.8-1.6 ma
<i>Paranthropus boisei</i>	2.3-1.2 ma
<i>Homo habilis</i>	2.4-1.4 ma
<i>Australopithecus africanus</i>	3.3-2.5 ma
<i>Australopithecus afarensis</i>	3.9-2.9 ma
<i>Sahelanthropus tchadensis</i>	7-6 ma
Pitldown Man	Fraud

Student prior knowledge of evolution, human evolution, and hominid skulls.

My students brought relevant prior knowledge to the hominin skull learning experiences, that I needed to identify as I was committed to constructivist learning theory. This prior knowledge dealt with evolution, human evolution, 3-D skulls, and perceptions of conflict.

Students brought prior knowledge of evolutionary concepts to the hominin skull learning experiences because we studied the topic earlier in the school year, prior to my research study. This earlier evolution unit was prescribed by our state standards (GPS, 2006), that required students to understand that species have changed over time, explained by the theory of natural selection, and supported by fossil evidence (GPS, 2006). The learning experiences completed by students to learn about these standards included: a) studying common natural selection examples of Darwin's finches, giraffes, and peppered moths of Manchester, b) researching and presenting the fossil ancestry of a chosen extant animal, c) and completing a case study of Darwin. I

anticipated that the fossil hominin learning experiences would support our previous explorations of broad evolutionary theory. I also anticipated that a study of human evolution would also broaden their understandings and address additional alternative conceptions.

Explicit instruction of human evolution prior to the extinct skulls learning experiences was minimal; reduced to a 10-minute lecture addressing the alternative conception regarding humans evolving from monkeys. I recall drawing a crude hominid phylogeny on the board to facilitate this discussion.

I knew students would be bringing prior knowledge of human evolution into my study from outside social influences. I also knew that this prior knowledge perceived human evolution in conflict with religious belief. I needed to consider this dynamic prior to instruction. Our school was located in a southeastern suburban area, with a mega-Baptist church as a centerpiece of the community. Many of my students and their families attended this church, and our school utilized some of the church's facilities during the school year (e.g., the chapel was utilized for awards night). This church sponsored a billboard set along a nearby highway, displaying imagery of a man morphing into a chimpanzee. The title of the billboard asked, "Are they making a monkey out of you?". I interpreted this sign as making a sarcastic jab at evolutionary theory and promoting creation. Ironically, two misconceptions were evident in the sign: a) the image of the chimpanzee was referenced as a monkey rather than an ape, and b) the message suggested the scientific notion that humans evolved from monkeys, rather than hominins or a common ancestor of humans and monkeys. This billboard may have represented some of the same prior knowledge brought in by my students--including misconceptions of evolutionary theory and an overall skepticism/fear of science.

The literature has documented student alternative conceptions indicative of their dichotomous views of evolution and religion/belief (e.g., If one accepts evolution, then they are immoral (Table 2.4). I considered these contextual and social factors when designing instruction during the hominin skull learning experiences. The main instructional strategies to deal with perceived conflict dealt with a) emphasizing the nature of science as a different way of knowing rather than a competitive force against religion, b) allowing students to explore the evidence supporting human evolution through discovery learning rather than teaching through more dogmatic approaches, responding to student comments regarding creation or alternative scientific views with respect.

I also considered the literature in identifying student prior knowledge of evolution, human evolution, and the nature of science when designing fossil hominin learning experiences. I selected from the list of alternative conceptions listed in Tables 2.1, 2.2, & 2.3, that could be addressed through the skulls curriculum. The alternative conceptions explicitly addressed in the fossil hominin learning experiences included:

- Evolution is based on little evidence (Daugher & Boujaoude, 1997; Sinatra, et al., 2003);
- Evolution is weak because it is just a theory (Daugher & Boujaoude, 2005; Nehm & Schonfeld, 2007);
- Evolution cannot be observed so it cannot be studied by science (Nehm & Schonfeld, 2007);
- Scientific theories are educated guesses, based on conjecture (Alters & Nelson, 2002; Dagher & BouJaoude, 2005);
- The fossil record is relatively incomplete/weak (Nehm & Schonfeld, 2007);

- Evolution occurs over shorter periods of time and not millions of years (Tamir & Zohar, 1991);
- Humans have evolved from monkeys (Daugher & Boujaoude, 1997; Woods & Scharmann, 2001);
- Humans evolved in the last 10,000 years (Newport, 2004);
- Evidence is trustworthy if it is obtained through direct observation only (so the evidence for evolution is not trustworthy (Dagher & Boujaoude, 2005);
- Scientific conclusions are truth (McComas, 1988)
- Science provides absolute proof (Chiapetta & Koballa, 2004; McComas, 1998)
- Science knowledge does not change (Anderson, 2007; Sinatra, et al., 2003).

An explanation of how these alternative conceptions were addressed will be explained in upcoming sections where learning experiences will be detailed.

The last aspect of student prior knowledge I considered dealt with prior knowledge of 3-D skulls. Because of the extant skull learning experiences, I knew students brought relevant prior knowledge and abilities to learning experiences (conducting comparative anatomy, differentiating between observation and inference, and conduct comparative anatomy). Therefore, I could challenge students to build on this prior knowledge and extend their demonstrated abilities. They would be required to complete similar learning experiences, such as presenting the life histories of skulls to peers, but would be challenged to expand their inferences, grapple with different NOS concepts, hypothesize about the designation of their skulls as either more ape-like or human-like, and develop phylogenies based on shared derived skull characters.

Human evolution, 3-D hominid skulls, and state/national standards.

The driving force of the hominin skull learning experiences were two performance tasks couched in the discipline of paleoanthropology, challenging students to present the life histories of extinct hominins to their classmates and justify student generated hominid phylogenies. However, state (GPS, 2006) and national standards (AAAS, 1993; NSES, 1996) also provided pedagogical guidance and structure, and included content, NOS, and inquiry standards.

The Hominin skull learning experiences relayed and related evolution, human body, and ecology content standards. The state evolution standards that were addressed included a) “Explain that physical characteristics of organisms have changed over successive generations”, b) “Describe ways in which species on earth have evolved due to natural selection”, and c) “Trace evidence that the fossil record found in sedimentary rock provides evidence for the long history of changing life forms (GPS, 2006, p. 7). The Benchmarks for Science Literacy (AAAS, 1993) included evolution standards for middle grades like our state standards. However, one standard was unique and particularly applicable to my study: “Fossil evidence is consistent with the idea that human beings evolved from earlier species” (AAAS, 1993, p. 129). The NSES (1996) provided more detailed evolution standards, which provided more guidance in the development of the hominin skull learning experiences. These standards challenged learners to recognize the diversity of living things, while also recognizing the “unity among organisms” based on an “analysis of internal structures, the similarities of their chemical processes, and the evidence of common ancestry” (NSES, 1996, p. 158). The NSES standards also challenged learners to consider fossils as evidence of the extinction of organisms, and extinction as a

common phenomenon in the history of living things on the planet. Ancillary to evolution content standards were content standards dealing with the human body and ecology (Table 3.8).

The inquiry standards explored in the extant skull learning experiences, were reapplied in the hominin skull learning experiences, with special emphasis on the inquiry standard regarding students' recognizing the relationship between explanations and evidence. More specifically, students continued to practice making observations and inferences as they described skull characters and reconstructed life histories based on these observations. Building on this activity, students were challenged to generate a hominin phylogeny, and justify their phylogeny (hypothesis) with observations of shared and derived skull characters.

The NOS concepts explored in previous learning experiences were re-examined during the extant skull learning experiences. These NOS concepts included distinguishing between observation and inference and understanding that scientific knowledge is empirically based, derived from studies of the natural world, and limited in the questions it can ask and answer (Lederman, 2007). For example, students observed extinct hominin skulls and developed likely inferences, and were challenged to explicitly make distinctions between the two scientific terms/processes. However, additional NOS were explored, given the potential of paleoanthropology to exemplify these NOS concepts. These new NOS concepts included scientific knowledge as tentative, theory-laden, and influenced by a larger social and cultural context (Lederman, 2007). Desilva (2004) asserted that paleoanthropology holds some of the greatest potential as a pedagogical instrument to deliver NOS concepts. He (Desilva, 2004) explained that even the experts differ in regards to the hominin relationships they depict through phylogenetic trees—which demonstrates the tentative nature of science. The story of Piltdown man also teaches NOS lessons. Piltdown man was presented as an extinct hominin in the earlier

part of the 20th century, but was later revealed to be a hoax (Lewin, 1987). This example exemplifies how social and cultural pressures can influence scientific knowledge, and more specifically that unethical science can and does happen. Skepticism, then, is an important component of science.

Hominin skulls learning experience one: Evolution anticipation guide.

Essential question posted: What do we know about evolution?

Approximate instructional contact time: 20 minutes pre intervention and 20 minutes post intervention.

Learning experience choice and design.

The first learning experience of the fossil hominin learning experiences was an anticipation guide like the NOS anticipation guide. This anticipation guide comprised of seven statements for students to consider and respond to through Likert scale and short answer response (Figure 3.11). The seven statements were derived from alternative student conceptions cited in the literature, and were chosen based the nature of the fossil hominin skull learning experiences to address such alternative conceptions. The anticipation guide prompts were open ended rather than multiple choice or fill-in-the-blank to encourage abstract thinking and sense-making, and to refrain from pin-holing student responses into pre-determined categories (Herbert & Nelson, 1977). The seven statements were also general statements regarding evolutionary theory, as I wanted students to grapple with the big ideas of science over details.

The students completed this anticipation guide pre-intervention in order to prime their brains for learning and establish student prior knowledge. We revisited these statements during the fossil hominin lessons during explicit instruction and teachable moments. Last, students completed this anticipation guide post intervention as a measure of their change in views.

Extinct Skulls: Anticipation Guide				
1. What scientists know about evolution is based on observation.				
a. 100% true	b. sort of true	c. I don't know	d. sort of false	e. 100 % false
Explain your answer: _____				
If you did not choose answer choice a, then how would you make the statement 100% true? _____				
2. Evolution can usually be observed during our lifetime.				
a. 100% true	b. sort of true	c. I don't know	d. sort of false	e. 100 % false
Explain your answer: _____				
If you did not choose answer choice a, then how would you make the statement 100% true? _____				
3. Evolution is just a theory.				
a. 100% true	b. sort of true	c. I don't know	d. sort of false	e. 100 % false
Explain your answer: _____				
If you did not choose answer choice a, then how would you make the statement 100% true? _____				
4. Scientists have collected very few fossils; hence, the fossil record is relatively incomplete.				
a. 100% true	b. sort of true	c. I don't know	d. sort of false	e. 100 % false
Explain your answer: _____				
If you did not choose answer choice a, then how would you make the statement 100% true? _____				
5. Scientists state that humans evolved from monkeys.				
a. 100% true	b. sort of true	c. I don't know	d. sort of false	e. 100 % false
Explain your answer: _____				
If you did not choose answer choice a, then how would you make the statement 100% true? _____				
6. One individual can evolve.				
a. 100% true	b. sort of true	c. I don't know	d. sort of false	e. 100 % false
Explain your answer: _____				
If you did not choose answer choice a, then how would you make the statement 100% true? _____				
7. A fact in science is a truth that never changes.				
a. 100% true	b. sort of true	c. I don't know	d. sort of false	e. 100 % false
Explain your answer: _____				
If you did not choose answer choice a, then how would you make the statement 100% true? _____				

Figure 3.11. Pre/Post Evolution Anticipation Guide. This was completed by students pre and post intervention, and visited throughout instruction.

Table 3.10
Explanation of 7 Pre/Post Prompts on Evolution Anticipation Guide

Prompt and curricular objective	Explanation of prompt development with optimal student response
1. What scientists know about evolution is based on observation.	I hoped students would agree with this statement, given their opportunities to observe fossil hominin skulls, and given our previous discussions of science as empirically based in both the NOS and extant skull learning experiences. I knew that students might be bringing alternative conceptions to the hominin skull learning experiences, however. For example, the literature documents that students think evolution is based on little evidence (Daughner & Boujaoude, 1997; Sinatra, et al., 2003); evolution is weak because it is just a theory (Daughner & Boujaoude, 2005; Nehm & Schonfeld, 2007); and, evolution cannot be observed so it cannot be studied by science (Nehm & Schonfeld, 2007). I hoped the students would, by post-intervention, respond to this statement as “100 % correct”, citing how they observed fossil hominin skulls to understand evolution. They could also answer, “sort of true”, explaining that our understandings of evolution are also dependent on hypothesis, such as hypothetical phylogenetic trees that may change with new fossil discoveries.
2. Evolution can usually be observed during our lifetime.	I hoped students would recognize the problematic aspect of this statement after the fossil hominin learning experiences. Students often harbor alternative conceptions that evolution occurs over shorter periods of time and not millions of years (Tamir & Zohar, 1991) and that human evolution has occurred over the last 10,000 years (Newport, 2004). I hoped that they would answer either “100% false” or “sort of false” to this statement. They would hopefully explain that evolution usually occurs over millions of years (as in the case of human evolution). However, they might also recognize that evolution has occurred over decades (such as through the example of the Manchester peppered moths (GPS, 2006)).
3. Evolution is just a theory.	I hoped students would recognize the problematic nature of this statement. However, according to the literature, many students would agree with this statement. They would agree that evolution is based on little evidence (Daughner & Boujaoude, 1997; Sinatra, et al., 2003) and evolution is weak because it is just a theory (Daughner & Boujaoude, 2005; Nehm & Schonfeld, 2007). By the end of the fossil hominin learning experiences, I hoped students would mark “100 false” to this statement and correct it by explaining that evolution is based on facts, such as our observations of hominin skulls. They might also explain that a scientific theory is based on an overwhelming amount of facts and explains phenomenon (such as the theory of natural selection explains species change).
4. Scientists have collected very few fossils; hence, the fossil record is relatively incomplete.	The literature has reported that students think the fossil record is relatively incomplete/weak (Nehm & Schonfeld, 2007). I hoped my students would come to refute this statement and recognize that the hominin fossil record is quite diverse. They would be studying eight extinct hominins through skull observations, and would also be creating their own phylogenetic tree before analyzing one (Stringer & Andrews, 2005, p.12), which included around twenty extinct hominins. An optimal student response would be “100% false” or “sort of false” with an explanation that the hominin fossil record is diverse. However, discoveries of new hominin fossils support the notion that the fossil record is incomplete. And, or because of the complex process of fossilization, the hominin fossil record will always be incomplete.
5. Scientists state that humans evolved from monkeys.	By the end of the fossil hominin learning experiences, students should refute this statement and explain that scientists state that humans and monkeys share a common ancestor.
6. One individual can evolve.	The literature has reported that students think that individuals adapt (Bishop & Anderson, 1990; Jensen & Finely, 1995; Crawford, et al., 2005). We explicitly discussed the falsehood of this notion in our earlier evolution unit. However, I wanted students to respond to this statement again in the context of human evolution. I hoped that by the end of the intervention students would respond, “100% false”, to this statement.
7. A fact in science is a truth that never changes.	The literature has reported that students think that science knowledge does not change (Anderson, 2007; Sinatra, et al., 2003), scientific conclusions are truth (McComas, 1988), and science provides absolute proof (Chiapetta & Koballa, 2004; McComas, 1998). Paleoanthropology demonstrates the falsehood of this statement. So, I hoped by the end of the intervention, students would respond “100% false”, to this statement and explain that science knowledge changes based on new discoveries.

Hominin skull learning experience two: Hominin fossil dig

Essential question posted: What is it like to go on a fossil dig?

Approximate instructional contact time: 20 minutes

Learning experience choice and design.

The purpose of the Hominin Fossil Dig learning experience involved creating a situated, authentic learning environment (Lave & Wenger, 1991; Rule, 2006) for students. In paleoanthropology, inquiries often begin out in the field at dig sites (Lewin, 1987). Fragments of fossils are discovered and assembled to create skull reconstructions for study. Likewise, I wanted my students to simulate a fossil dig to begin our inquiries into human evolution. I borrowed this lesson experience from my major professor who designed it. He took photographs of our 3-D fossil hominin skulls against backgrounds similar to the environments in which they were actually found. The photographs were then taken to a photography store to be converted into puzzles (Figure 3.12).

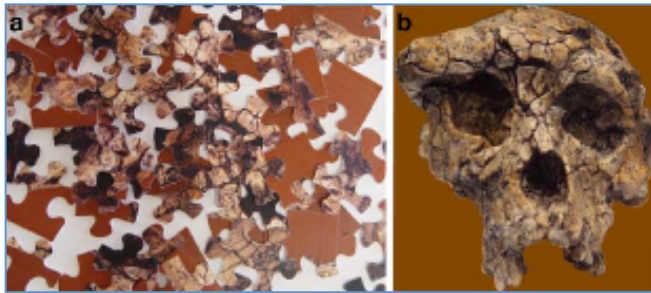


Figure 3.12. Unassembled and Assembled Hominin Fossil Puzzle. Image “a” shows an unassembled fossil hominin puzzle, and image “b” shows a completed puzzle.

I used nine puzzles (eight depicting fossil hominins and one of Piltdown man), so students worked in groups of two or three. One student in the group selected an unknown puzzle.

Collaboratively, students assembled their puzzle together, and their final 2-D skull image represented the fossil they would be studying throughout the fossil hominin skull learning experiences.

Students completed a summarizing activity (Marzano, Pickering, & Pollock, 2001) after assembling their puzzle. Students were directed to list two ways in which they were acting like scientists during the fossil dig learning experience. They were also prompted to write at least two ways in which the activity was not like a real fossil dig. I hoped students would make some of the following connections: a) they were working collaboratively like real paleoanthropologists, b) they were matching up skull characters in order to assemble their fossil like real paleoanthropologists, c) the fossil dig was not authentic in that rarely are all “pieces” of entire hominin skulls discovered, d) the fossil dig was not authentic in that a paleoanthropologist often finds other mammalian fossil fragments in the same dig area. After completing the summarizing activity in groups, I led an all-class discussion, using the overhead projector to compile and discuss student responses.

The next learning experience introduced students to their 3-D hominin fossil, and challenged them to use a dichotomous key to review and apply osteological terminology, and determine the scientific name of the specimen.

Hominin skull learning experience three: Hominid dichotomous key

Essential question posted: How do we use a dichotomous key to identify the species of our fossil hominin discovery?

Approximate instructional contact time: 15 minutes

Learning experience choice and design.

After completing their fossil dig and assembling their fossil find into a 2-D picture, students matched their picture to the 3-D fossil hominin skull. They used a dichotomous key (Figure 3.13) to determine the species name of their specimen. The application of osteological terminology learned in the extant skulls learning experiences was required (e.g., one couplet on the dichotomous key required students to determine if their skull had a prominent, minimal or absent sagittal crest). The students were also challenged to make quantitative measurements with measuring tape and calipers to move through the dichotomous key. For example, they had to determine the width of the back mandibular molar. Some couplets on the dichotomous key introduced new skull characters not learned in the extant skull learning experiences (e.g., zygomatic arch). Therefore, some direct instruction was required to help students through these couplets, and students broadened their vocabulary of skull characters through this learning experience.

After keying out their fossil hominin find, the students practiced pronouncing the scientific name of their fossil find. We went around the room, and student groups shared the scientific name of their find with others in the class. Corrections to mispronunciation were made, and student inferences were considered regarding the meaning of the scientific name of their skulls. Future learning experiences required students to refer to their skull find with the scientific name.

At this point, I also let students know of an individual project they would be completing at home. I challenged them to come up with one question that they would like to answer about their hominin fossil find. I explained that they could begin researching this question at home on

the Internet, or begin coming into school early to conduct library research. Their task was to create a PowerPoint presentation, presenting their research question and findings, to be emailed to me by the end of the hominin skull learning experiences. I would remind students of this assignment every day, and post the assignment on the board for homework.

TAXONOMIC KEY FOR HOMINIDS		
1A.	Foramen magnum at angle to skull (not directly under base); spinal cord exit at angle to skull – Quadrupedal Locomotion.....	go to 2
1B.	Foramen magnum horizontal to base of skull; spinal cord exit perpendicular to skull – Bipedal Locomotion.....	go to 4
2A.	Nasal cavity triangular.....	go to 3
2B.	Nasal cavity not triangular.....	<i>Gorilla gorilla</i>
i.	Sagittal crest prominent, large canine teeth.....	male
ii.	Sagittal crest reduced, small canine teeth.....	female
3A.	Zygomatic arch robust (width at midpoint of arch 9-16 mm.....	<i>Pongo pygmaeus</i>
3B.	Zygomatic arch gracile (width at midpoint of arch 5-9 mm.....	<i>Pan troglodytes</i>
4A.	Sagittal crest prominent	<i>Paranthropus boisei</i>
4B.	Sagittal crest minimal or absent.....	go to 5
5A.	Cranium (length of skull from brow to ridge to lower occipital bone) small; less than 250 mm.....	go to 6
5B.	Cranium (length of skull from brow to ridge to lower occipital bone) large; greater than 250 mm.....	go to 9
6A.	Brow ridge / supraorbital torus prominent	go to 7
6B.	Brow ridge / supraorbital torus reduced or absent	go to 8
7A.	Subnasal prognathism intermediate.....	<i>Australopithecus africanus</i>
7B.	Subnasal prognathism reduced / weak.....	<i>Sahelanthropus tchadensis</i>
8A.	Mandible length greater than 120 mm.....	<i>Australopithecus afarensis</i>
8B.	Mandible length less than 120 mm.....	<i>Homo floriensis</i>
9A.	Brow ridge / supraorbital torus prominent	go to 10
9B.	Brow ridge / supraorbital torus reduced or absent	go to 12
10A.	Cranium (length of skull from brow to ridge to lower occipital bone) large; greater than 315mm.....	<i>Homo neanderthalensis</i>
10B.	Cranium (length of skull from brow to ridge to lower occipital bone) small; less than 315 mm.....	go to 11
11A.	Back mandibular molar width $\approx$ 10 mm or less.....	<i>Homo ergaster</i>
11B.	Back mandibular molar width $\approx$ 11 mm or more.....	<i>Homo erectus</i>
12A.	Mandible length $\approx$ 115 mm.....	<i>Homo sapiens</i>
12B.	Mandible length $\approx$ 140 mm.....	Pitldown Man (paleontological fraud)

Figure 3.13. Hominid Dichotomous Key. Students keyed out their fossil skull to apply their knowledge of skull characters, make scientific measurements, and identify the scientific name of their fossil find.

Hominin skull learning experience four: Hominin skull drawings

Essential question posted: What can we learn about our hominin skull?

Approximate instructional contact time: 90 minutes

Learning experience choice and design.

This learning experience challenged students to look closely at their hominin fossil finds, generating evidence and explanations for subsequent presentations to the class. Students worked individually to generate detailed drawings of their hominin skull find (Figure 3.13). They were reminded that drawing is another form of observation, so detail, accuracy, and clarity were important to keep in mind. Students were instructed to create scaled drawings, include the scientific name of their specimen, label the teeth and record the dental formula, and generate three questions for future inquiry. Next, they were instructed to complete an observation/inference chart (Figure 3.13) identical to the chart they completed for their extant skull drawings. Students were encouraged to work collaboratively when determining observations and generating inferences.

Hominin skull learning experience five: Hominin skull presentations

Essential question posted: What can we learn from each other about fossil hominin skulls?

Approximate instructional contact time: 60 minutes

Learning experience choice and design.

The hominin skull presentations challenged students to present their hominin skull to their classmates, creating a simulated environment of a scientific symposium. Students presented in research teams and held a question and answer session post presentation to field comments from the audience.

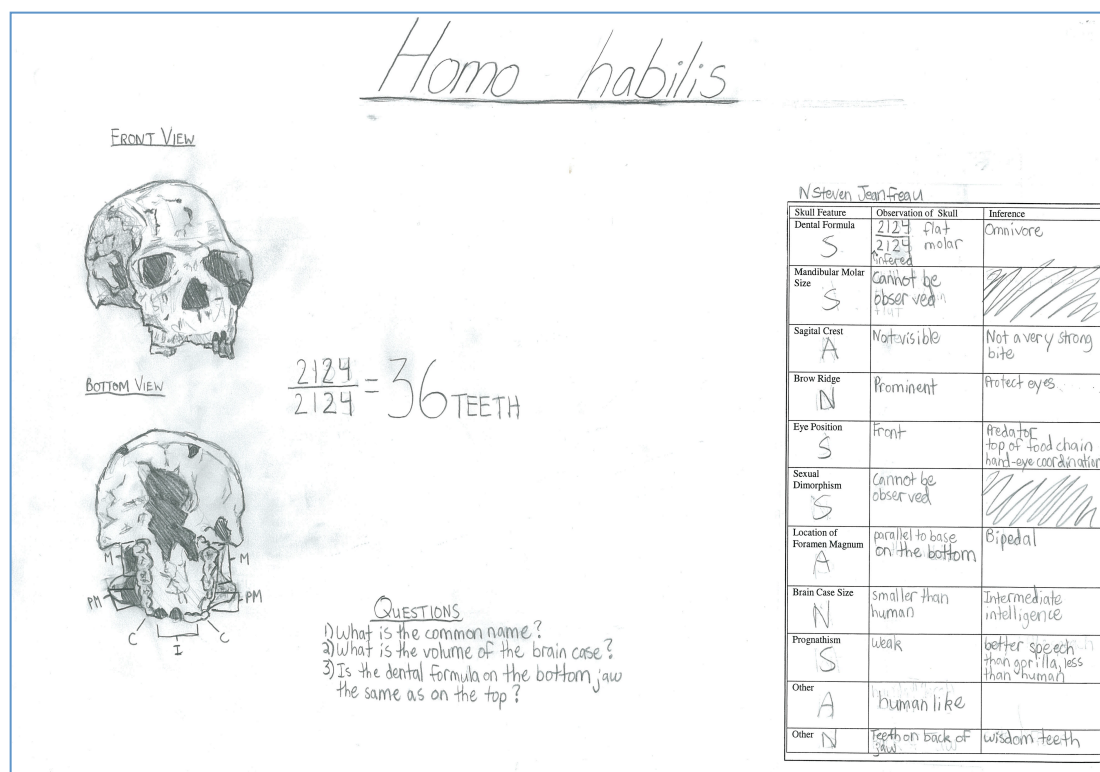


Figure 3.14. Student Drawing of a Fossil Hominin. Process included labeling the scientific name, labeling the teeth, recording the dental formula, filling out an observation/inference chart, and generating three questions for future inquiry.

While in the audience, students filled out data charts on each hominin (Table 3.12) to be used in future learning experiences to create hominin phylogenies.

More specifically, the hominin skull presentations were designed to serve as a teaching and learning, scaffolding, and assessment tool. As a teaching and learning tool, the hominin presentations provided a format for teaching and learning about inquiry, NOS, and evolution. Students were encouraged to engage in inquiry, specifically the “essential features of inquiry” such as posing questions, giving priority to evidence, formulating explanations from evidence, and communicating and justifying these explanations to others (NRC, 2000, p. 29). Figure 3.14 shows a student example of the evidence and explanations he collected to present to peers, which would create a ripe environment for discussing NOS and evolution concepts. The potential for

NOS conversations was ripe during the hominin skull presentations. For example, the nature of science concept of science (and evolution) as empirically based could be emphasized, over and over again, after each presentation. The notion of science as subjective and influenced by culture could also be explicitly addressed after the presentation Piltdown man, the paleoanthropological fraud. The pedagogical design of the hominin skull presentations was also meant to spark conversations regarding the big ideas of evolution, such as deep time, speciation, and extinction. For example, *Sahelanthropus tchadensis*, dated to between seven and six millions years ago, paints a picture of human ancestors roaming the planet over millions of years rather than within the last 10,000 years (Newport, 2004). Speciation can also be exemplified when comparing the similarities yet differences in hominin skull characters. And, recognizing that all nine hominins presented went extinct, illustrates extinction as a common trend in the history of life on our planet.

The hominin skull presentations served as scaffolding tool, building knowledge and skills for future learning experiences dealing with the construction of hominin phylogenies. During the presentations, each student was required to fill out a data chart on each hominin presented (Table 3.12). So by the end of these presentations, each student had nine hominin charts. This data would later be used to identify trends and relationships among skulls to construct a hominin phylogeny.

Last, the hominin skull presentations were designed to serve as a formative and summative assessment. During student presentations, I planned to take note of student expressions of normative and alternative conceptions, and use the time between presentations to explicitly applaud or address these conceptions.

Table 3.11 <i>Table Completed by Audience Members for Each Hominid Presentation</i>	
Species name and age:	
Dental formula:	Sexual dimorphism?
Herbivore, omnivore, or carnivore?	Level of intelligence?
Bipedal or quadrupedal?	Nocturnal or diurnal?
Sagittal crest present?	Gorilla-like or human-like or both?
Brow ridge reduced or pronounced?	Other:

These presentations were also designed as a summative assessment, giving presentation groups a quantitative grade using a rubric, identical to the rubric used to assess the extant skull presentations (Figure 3.17). This quantitative grade would then be compared to their grade for the extant skull presentations to measure student improvement. My methods section describes the development and results of this summative assessment more completely.

Hominin skull learning experience six: Searching for Lucy

Essential question posted: What can we learn from *Lucy's* story?

Approximate instructional contact time: 60 minutes

Learning experience choice and design.

In this learning experience, I showed the film “In Search of Human Origins, Part 1: The story of *Lucy*” (Gunton, 1994). This film chronicles the discovery of *Australopithecus afarensis* by Don Johansson, and his quest to better understand Lucy, and our human origins. The film supplemented previous student experiences with retrodictive inquiry and NOS concepts, such as science as tentative. Moreover, the film challenged students in new thinking, in regards to conceptualizing the common ancestor between extant humans and chimpanzees and what it

means to be human. Table 3.12 lists the questions students answered during the video and the pedagogical purpose behind each question.

Table 3.12 <i>Rationale for “Lucy” Video Prompts</i>	
Video Question	Pedagogical purpose of question
1. What do you see the scientists doing in the video that we have done or know about?	I wanted student to recognize that they simulated the same activities of the scientists in the video, such as assembling fossil pieces, making observations and inferences of skull characters, and engaging in retrodictive inquiry to reconstruct our human past.
2. Don Johansson refers to “the missing link.” What does he mean by the missing link?	The term “missing link” was used often in the video to refer to the common ancestor linking contemporary humans and chimpanzees. I wanted students to think about the term “missing link”, and begin conceptualizing the meaning of common ancestry.
3. What did the scientists predict would be the important characteristic of the missing link?	The film demonstrated the tentative nature of science. “Lucy” showed scientists that bipedalism rather than large brain case size may have been the key feature driving human origins. I wanted my students to consider this example of the tentative nature of science.
4. How and why did the scientists’ prediction about the missing link change?	This question has the same student outcome as question three.
5. What do you think it means to be human?	The scientists in the film considered this question. I wanted my students to join in this inquiry, by suggesting their own hypothesis. I hoped they would recognize the importance of bipedalism as one of several key features of being human.
6. If you were Don Johansson, would you have classified Lucy as an ape-like <i>Australopithecine</i> , an early member of <i>Homo</i> , or both? Explain.	This question challenged students to engage in inquiry, making a claim and then basing the claim on evidence.
7. What unanswered questions do you still have?	This question was designed to support an “essential feature of inquiry” because students were encouraged to pose their own questions (NRC, 2000, p. 29).

Hominin skull learning experience seven: Wall of one million asterisks

Essential question posted: What does one million look like?

Approximate instructional contact time: 10 minutes

Learning experience choice and design.

This lesson was designed to help students conceptualize the concept of one million. Conceptualizing one million might help students a) grasp concepts of deep time and macroevolution important to evolutionary theory (Catley, 2006), and b) confront alternative conceptions such as humans living over the last 10,000 years (Newport, 2004) and evolution occurring over short periods of time, rather than over millions of years (Tamir & Zohar, 1991). I borrowed this lesson idea from a web-based resource, Understanding Evolution (2012), developed by the University of California Museum of Paleontology. This lesson required me to fill one word document with as many asterisks as possible, single-spaced, and then print off the number of pages required to show one million asterisks. One page held 3312 asterisks, so I printed off 302 pages and hung them consecutively out in the hallway by my classroom. I had students come out in the hall and sit down in front of the one million asterisks. I asked the following questions to prompt discussion regarding concepts of deep time:

- If this wall of asterisks represents the last one million years on this planet, where would your lifespan be represented?
- Where would the lifespan of your parents and grandparents be represented?
- How far back on the wall would we have to go to represent the beginning of recorded history?
- How far back on the wall would we have to go to represent the hominin fossil you discovered?

- How far back on the wall would we have to go to represent the beginning of human origins?
- How far back on the wall would we have to go to represent the beginning of life on the planet, of the age of the earth, of the age of the universe?

For each question, I called on student volunteers to come to the wall of asterisks to show their answers to their peers and begin discussion. Many answers could not be shown on the wall, as it only represented the last one million years, so we had to extrapolate and visualize in these instances.

Hominin skull learning experience eight: Hominid hallway timeline

Essential question posted: How can we create a hominin family tree using our 3-D skulls to show evolutionary relationships?

Approximate instructional contact time: 60 minutes

Learning experience choice and design.

The purpose of this learning experience introduced students to the concept of phylogenetic trees. Students took their fossil skulls out in the hallway. We also brought the gorilla, chimpanzee, and *Homo sapien* skulls, because we were going to create a hominid phylogenetic tree. We used the tiles on the floor as chronological markers, with each tile representing 50,000 years. I began the activity by asking students where the extant skulls should be placed, leading to a conversation of contemporary species and their lateral orientation at present time on a phylogenetic tree. We stepped back in time from there, and each student brought their skull up in chronological order, placing it on the appropriate tile (Figure 3.15). All students filled out a handout while we completed this learning experience. The handout consisted of a two-page timeline. Students used this graphic organizer to help shape a crude phylogenetic

tree. They recorded the scientific name of the skulls on their papers, in the appropriate sequence and place according to time. They also drew in lines to show evolutionary relationships among skulls.



Figure 3.15. Hominid Hallway Phylogeny. Student-participants collaborated to create a hominid phylogeny using hallway tiles to mark off time. They recorded the phylogeny on their own paper.

I posed several questions for consideration during the Hominid Hallway Timeline learning experience:

- Looking at this phylogeny, how would you respond to the comment “Humans evolved from monkeys”
- Which hominins may have walked on the planet at the same time?
- Which hominins went extinct?
- Why do you think *Homo sapiens* is the only hominin living today?

- What common features do all of these hominins share?
- Which hominins have features that make them different from the rest of the hominins?
- Who evolved from whom?
- Is evolution just a “theory”?

The discussion that followed these prompts addressed student alternative conceptions, and scaffolded student learning towards learning experience nine, challenging student to propose their own hominid phylogenetic tree based on shared and derived characters.

The students and I returned to the classroom to complete a summarizing activity for the Hominid Hallway Timeline learning experience, lasting approximately ten minutes. Each student received a copy of a hominin phylogenetic tree copied from Stringer and Andrews (2005) (Figure 3.16). Students considered the following questions displayed on the overhead projector at the their tables:

1. What span of time is represented by the timeline?
2. Find *Homo sapiens* on the phylogeny. Which two extinct species were contemporaries with *Homo sapiens*?
3. According to the tree, how long has *Homo sapiens* roamed the planet?
4. According to the tree, which species is the most recent ancestor to *Homo sapiens*?
5. Find “Lucy” or *Australopithecus afarensis* on the phylogeny. Is “Lucy” the “missing link” between humans and the other extant apes (chimpanzees and gorillas)?
6. What would happen to this phylogeny if there were a new hominin fossil find?
7. How does this phylogeny represent the idea that science can change?
8. True or false. Scientists have collected few hominin fossils, so the fossil record is not helpful in telling us about our human past. Explain.

We discussed student answers to these prompts to summarize this lesson experience and end class.

Hominin skull learning experience nine: Justifying Hominid Phylogenies

Essential question posted: What evidence can you provide to justify your hominid phylogeny?

Approximate instructional contact time: 45 minutes

The purpose of this learning experience was to build student experiences regarding the development of phylogenetic trees, to assess students' abilities to engage in inquiry, and more specifically to engage in formulating explanations from evidence—an essential feature of inquiry (NRC, 2000). This learning experience challenged students to justify the phylogenies they created the previous day during the Hominid Hallway Phylogeny learning experience.

Whole-class discussion transpired first. Students were asked to take a look at their phylogenies, and begin thinking about how the hominid fossils might be related. Students were told that solid and dashed lines could be added to their phylogeny to demonstrate evolutionary relationships. Students were also directed to consider skull characters that might indicate evolutionary relationships. Students were directed to finish their phylogeny. Then, they were directed to write a paragraph or two on the back of their paper to justify their phylogeny based on evidence. Students were informed that they would be assessed based on how well they used evidence to justify their claims, rather than on if they provided a “right answer”.

Figure 3.16. Stringer and Andrew's Hominid Phylogeny for Analysis. Students-participants shared their ideas regarding what was being show by the phylogeny and answered teacher directed questions.

Hominin skull learning experience ten: Independent research

Essential question posted: What questions did you pose about your hominin fossil find and what did you learn?

Approximate instructional contact time: Ongoing for homework

The purpose of this learning experience challenged students to engage in one of the essential features of inquiry in which “Learner engages in scientifically oriented questions” and “Learner poses a question” (NRC, 2000, p. 29). The hominin skull learning experiences prior to this final learning experience were also framed by scientifically oriented questions, but I developed these questions within the framework of Backwards Design (Wiggins & McTighe, 1998). I wanted this final learning experience to allow for greater student choice in posing their own scientifically oriented question to research and present. Ideally, I wanted students to present their findings at a mock scientific symposium, but the school year came to a close before we could do so. Therefore, students emailed me the PowerPoint presentations that they created from home, showing their unique question and their findings.

This learning experience was also designed as an assessment piece, to glean the types of questions students could ask and answer out of their experiences with the curriculum in this study. Could they pose logical questions capable of being answered? What types of questions would they pose? What topics did they want to know more about? The findings of this learning experience were reported in the methods section of this study.

Data Collection and Data Analysis Methods

Introduction

In this section, I discuss the data collection methods I used for three major data collection efforts: a) a NOS Pre/Post questionnaire, b) extant and extinct skull student presentations, and c) pre/post focus group interviews.

NOS Pre/Post Questionnaire

The following subsections organize a discussion regarding the NOS pre/post questionnaire: a) introduction, b) NOS questionnaire construction, c) NOS questionnaire administration, d) NOS questionnaire validity and reliability, and e) inductive analysis of NOS questionnaire data.

Introduction.

A NOS pre and post questionnaire (also the anticipation guide in lesson one of the NOS unit) (Figure 3.1) served as a research tool in two important ways. First the NOS pre and post questionnaire served as a conventional open-ended pre/post-questionnaire to identify student views and any changes in these views. This student-generated data would inform research question number two, six, and seven: What student views of the Nature of Science are communicated as they apprentice as paleoanthropologists, How do my conceptions of teaching and learning of human evolution change during the study as I engage in teacher research?, and How should the curriculum intervention be modified based on teacher and student data sources? Also, the post NOS questionnaire results would serve as a guidepost for future focus group interviews with students.

I reviewed several NOS questionnaires during the development on my own (Aikenhead, Ryan, & Flemming, 1987; Ryan & Aikenhead, 1992; Lederman & O'Malley, 1990; Lederman,

Abd-El-Khalick, & Bell, 1998; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman & Khisfe, 2002; Kang, Scharmann, & Noh, 2005; Liu & Lederman, 2002; Liang, Chen, Chen, Kaya, Adams, Macklin, & Ebenezer, 2005). However, it became apparent that I would have to develop a unique NOS questionnaire tailored to my unique curricular intervention and research situation.

First, most of these instruments were designed for one-time implementation to identify the full range of student NOS views or for large-scale normative purposes (e.g., Liang et al., 2005). Several of the instruments were administered pre and post of instruction (e.g., Lui & Lederman, 2002), however details of the curricular intervention were absent or implicitly aligned to the items on the instrument. Second, most of these instruments were designed for high school or pre-service learners (e.g., Aikenhead et al., 1987; Lederman & O'Malley, 1990; Lederman, 1999, Lederman et al., 2002) and contained language steeped in advanced content knowledge (e.g., atomic theory and astrophysics in Lederman et al., 2002). One instrument only pertained to the tentative nature of science (e.g., Lederman & O'Malley, 1990), while most pertained to an array of NOS concepts (e.g., Kang, Scharmann, & Noh, 2005; Lederman, 1999; Liu & Lederman, 2002; Lederman & Khisfe, 2002).

The instruments designed for middle school learners contained similar issues limiting their transfer to my particular research situation. The questionnaires were either designed for large-scale normative purposes (Kang, Scharmann, & Noh, 2005; Lederman 2007), examined student views on five or more NOS concepts (Lui & Lederman, 2002; Kang, Scharmann, & Noh, 2005; Lederman 2007), or were poorly couched in a curricular intervention based on student experience (e.g., Liu & Lederman, 2002). Last, I refrained from borrowing single items from these instruments for several reasons. Some items were framed by scenarios misaligned to my

curricular objectives (e.g., gold mining in Kang, Scharmann, & Noh, 2005). Other items focused on NOS concepts other than the ones in my curriculum (e.g., science as a creative endeavor, the nature of a scientific theory).

Overall, my questionnaire needed to focus on a subset of NOS concepts. The questionnaire items needed to be aligned to instruction so that students could have an opportunity to learn the concepts being measured. Last, my NOS instrument was a smaller piece in a larger data collection effort, and items needed to correlate to items on future questionnaires dealing with evolution and paleoanthropology.

NOS questionnaire construction.

My questionnaire (Figure 3.1) focused on NOS as: (a) empirically based, (b) concerned with the natural world, and (c) one way of looking at the world. Participants responded to five prompts. Prompt 1, 2, and 4 related to science and observation, prompt 3 related to science and the natural world, and question 5 related to science as one way of knowing. The five prompts were problematic in some way, and were either derived from the alternative conception literature, borrowed from items on other invalidated NOS instruments, or derived from recommendations in the literature. I used statements rather than questions—similar to the NOS instrument developed by Aikenhead et al. (1987) and in line with the theory behind the use of anticipation guides as explained previously. Table 3.14 provided detailed explanations for how and why a prompt was used, and the optimal student response to each prompt.

My questionnaire required students to respond to each of the five statements in three ways. First, students responded to a Likert item (a. 100% true b. sort of true, c. I don't know, d. sort of false, e. 100% false)-a forced choice method (a method also used by Liang et al. 2005), encouraging participants to commit to a certain response, enabling me to categorize responses

into initial analytical piles. Second, students were guided to explain their Likert item response. Eliciting student explanations addressed concerns about pencil-paper, forced-choice instruments, which fail to check and probe students' views (Driver et al, 1996). Third, students were guided to change the initial prompt if they thought it to be anything other than 100% true. Such strategy encouraged students to further expand on their explanations. I intended for the questionnaire to help discover the diverse set of student viewpoints to inform instruction. As suggested by other researchers (e.g., Lederman and O'Malley, 1990; Lederman, et al., 1999; Lederman, 2007), I also used student questionnaires as an initial entrance into focus group interviews.

Table 3.13 <i>NOS Questionnaire Prompts with Explanation</i>	
Prompt and curricular objective category	Explanation of prompt development with optimal student response
1. Science knowledge is based on beliefs.	Some philosophers of science have argued that science is based on a system of beliefs; what scientists choose to observe and how they interpret data is theory laden (Kuhn, 1970). I mentioned this notion to my students several times throughout the year (e.g., via Dian Fossey unit) and again in the NOS learning experiences. However, I did not have an explicit learning experience—focused on science as subjective—in this NOS unit. Again, the focus was on science as an empirical way to interpret the natural world. Therefore, I expected my students to recognize ways to improve statement one. In simplest terms, I hoped students would change the word “belief” to “observation”. I would also accept “evidence”, “facts”, and “data” as equivalents; no explicit distinction was made between these terms during instruction, and no clear distinction among these terms is explicated in the standards. Additional merit would be given to students who also recognize the subjectivity involved with humans conducting science. The optimal aligned Likert scale response would be “d. sort of false.”
Science knowledge is empirically based	
2. Science knowledge is based only on observation	I hoped students would recognize the problematic aspect of this statement. Even though observation is quintessential to scientific knowledge, it forms the basis of inferences, hypotheses, theories, and explanations, which extends scientific knowledge. Chiappetta and Koballa (2006) have explained, “the body of knowledge formed by scientists is the result of extensive observations that eventually coalesce into concepts, principles, and theories” (p. 98). Such is the case with our understandings of human evolution. Our observations of hominin skull characters form the basis for reconstructing hominin life histories. The aligned Likert scale response might be “b. sort of true”, “d. sort of false”, or “e. 100% false”.
Science knowledge is empirically based	
3. Science can answer all	I wanted students to recognize the boundaries of science. Science includes inquiries dealing with the natural world, rather than the supernatural and metaphysical. The aligned Likert scale response should be “e. 100% false”.

questions.	
Science is concerned with the natural world	
4. Data collected in science are collected with honesty, clarity, and accuracy	All enterprises include practitioners who cheat, cut corners, and/or distort the research process in some way. Science is no exception. Consider “Piltdown Man”, a fake hominin fossil fabricated in 1912, composed of an orangutan lower jaw and human skull. The skull was used to support the hypothesis that the human brain evolved before bipedalism (Lewin, 1987). However and also in line with other enterprises, science has standards of practice--making careful observations (AAAS, 1993, p. 10; Chiappetta & Koballa, 2006), making accurate measurements (AAAS, 1996, p. 10), basing claims on evidence, communicating findings in a thorough way, “intellectual honesty” (NRC, 1996, p. 170), evaluating the work of other scientists, and peer review (NRC, 1996, p. 171). The students and I also explicitly discussed <i>how</i> to make observations throughout the year and during the NOS learning experiences (e.g., using detailed, specific language and measuring to the nearest 10 th 's place). The aligned Likert scale response would be “b. sort of true”, or “d. sort of false”.
Science knowledge is empirically based	
5. Science must follow certain rules	The purpose of this prompt was to allow students to recognize science as a distinct enterprise, framed by certain rules or standards of practice which all scientists should abide by such as entertaining questions pertaining to the natural world, making detailed observations, making accurate measurements, basing claims on evidence, communicating findings for peer review, etc. I used the word “rule”, as the word “assumptions” was not in line with the working language of 7 th graders, and the word “guidelines” insinuated that scientific standards of practice are negotiable. Meadows (2007) also used the word “rules” in referring to the unique epistemological perspective of science to his secondary students. Adhering to a strict scientific method would not pertain to a “rule” of science. Likert scale items “b. sort of true” or “d. sort of false” aligned with this explanation.
Science is one way of knowing	

NOS questionnaire administration.

I administered the NOS questionnaire to students on two occasions. Students completed the questionnaire the first time prior to any NOS learning experiences. Students worked individually. I instructed students to do the best that they could on the questionnaire, and that there were no right or wrong answers. I told them that I was looking for their ideas, and to communicate those ideas as clearly and completely as possible on their handout. I did not give a time limit for completing the questionnaire; students had more than enough time to fill out the questionnaire without any time pressures or constraints.

I administered the NOS questionnaire a second time to students after we fulfilled all four NOS learning experiences. I gave the same instructions to students described during the first administration of the instrument.

NOS questionnaire validity and reliability.

The questionnaire prompts were developed given my unique NOS curricular objectives. Thus, my questionnaire was objective or criterion referenced, aligned to concepts I wanted students to know by the end of the NOS intervention. The purpose of the questionnaire was to identify whether students gained more normative views of the NOS due to the NOS curriculum intervention, rather than to rank students as in a normative-referenced assessment. I also looked to the alternative conception literature, the GPS, and recommendations made in the literature to help frame questions in a theoretically and research-based way—toward content validity. I also constructed statements keeping in mind the developmental level of my students, and wording statements as simply as possible—toward face validity. Table 3.15 showed how each questionnaire item was referenced to curricular objectives and couched in the science education literature.

Table 3.14 <i>NOS Questionnaire Item and Reference</i>		
Questionnaire Item	Item link to curricular objective	Item link to literature
1. Science knowledge is based on beliefs.	Science knowledge is empirically based.	This item was modified from item 1 (“Science is a system of beliefs”) of Chiappetta and Koballa’s (2004, p. 59) “Myths of Science” quiz.
2. Science knowledge is based on observation.	Science knowledge is empirically based.	I developed this prompt based on readings in the literature emphasizing that science is empirically based (e.g., Ziman, 1978) and based on the alternative conception literature that has suggested students discount the empirical nature of science when learning about evolution (e.g., Daugher & Boujaoude, 2005)
3. Science can answer all questions.	Science knowledge is concerned with the natural world.	This statement was modified from McComas’s (1998) list of NOS myths. “Myth 8: Science and its methods can answer all questions” (p. 61).
4. Data collected in science are collected with honesty, accuracy, and clarity.	Science knowledge is empirically based (data/evidence/observations must be collected with honesty, accuracy and clarity).	I developed this item by modifying one of the GPS standards: “Students will... a. Understand the importance of—and keep—honest, clear, and accurate records in science” (GPS S7CSI, p. 3).
5. Science must follow certain rules.	Science is one way of knowing.	I developed this item based on the recommendations of Anderson (2007) and Meadows (2007). Anderson recommended that learners understand the difference between science and other epistemologies. I chose to use the word “rule” as recommended by Meadows.

I established criterion validity using the same approach as Lederman and O’Malley (1990) who were faced with a similar research scenario. Their VNOS-A instrument was in the early stages of development as my own. They validated their VNOS-A by comparing item responses to responses in follow-up interviews. Findings from the use of the VNOS-A were used in the development of future NOS instruments. Like Lederman and O’Malley, my questionnaire findings were used to make questionnaire improvements. Unlike Lederman and O’Malley, my

findings were also used to indicate changes in students' views of NOS, and to make future curricular modifications.

Estimating reliability was more difficult. Estimating reliability through double administration methods such as the test-retest method was not feasible due to time constraints in the classroom; there was only time to administer the questionnaire pre and post curricular intervention. Single administration methods for estimating reliability were equally challenging. The split-half and internal consistency methods required a substantial amount of questionnaire items and sample sizes in order to conduct statistical analyses. Examples from the literature illustrated this point. Dillashaw and Okey (1980) included 36 items in their Test of Integrated Process Skills II, administering it to 709 participants. Nadelson and Southerland's (2010) included 28 items in their Measurement of Understanding of Macroeolution (MUM) and administered it to 795 participants. These assessments that estimated high reliability were also developed over multiple trials with final implementations of multiple-choice items. My questionnaire was in the early stages of development requiring short answer responses and follow-up interviews. My questionnaire consisted of five items, a suitable number of items for the attention span of middle school participants and in line with other short answer NOS measurements administered to this same age group (e.g., Lederman & Khisfe, 2002). My sample size was 34, a small number to make reliability and representation claims.

Overall, I made a similar assumption as Aikenhead et al. (1987); my NOS instrument served as diagnostic tool rather than a normative tool. The purpose of my instrument was to unpack the range of students' views about particular aspects of NOS to identify learning gains and inform future classroom instruction. I made no assumptions that the findings would be representative of other student populations. Last, I understood that questionnaire development

was an ongoing and iterative process. For example, Lederman's NOS instrument (VNOS) (Lederman, 2007) has been modified over the course of more than a decade.

Inductive analysis of NOS questionnaire data.

I analyzed questionnaire data using inductive analysis (Patton, 2002), a process of looking directly at collected observations, and deriving emergent understandings from these observations. The inductive analysis approach differs from hypothetical-deductive approaches in key ways. While deductive/experimental design approaches begin with the identification of main variables and hypotheses before data collection, inductive analysis begins with an exploration of the data; relationships among variables and testable hypotheses manifest after the inquirer explores and comes to understand the data. Overall, data in inductive analysis are not "pigeon-holed" into pre-existing, closed, analytical scaffolds (e.g., multiple choice measurement tools or Likert item questionnaires). Data are comprehensively considered and combined thematically giving rise to emergent categories for consideration.

I borrowed from Grounded Theory methods (Glaser & Strauss, 1967; Charmaz, 2006; Grbich, 2007) to systematically and thematically aggregate my questionnaire data towards the development of claims regarding teaching and learning outcomes. Patton (2002) has explained that grounded theory methods can be applied in many qualitative methodologies, and not just the grounded theory methodology. Grounded theory methods (versus the methodology) provide "coding procedures" (Corbin, 1998. P. 13) for making sense of masses of qualitative data, in an attempt to keep the analysis "grounded in the empirical world" (Patton, 2002, p. 127).

I analyzed my questionnaire data in three major phases. First, I conducted initial coding (Charmaz, 2006) of questionnaire responses to assign specific, nascent codes to data. For example, one student responded to the NOS questionnaire item number one (*Science is a system*

of beliefs), stating, “When you think about it, everything is an observation. Whether you observe the test strip, the planets in our solar system, or an animal (such as a gorilla) at the zoo”. I assigned an initial code of “observation only” to this response, to summarize the students’ idea that science relies on observation versus belief with no exception. This initial code of “observation only” also demonstrated how my initial codes were “*in vivo*” (Charmaz, 2006, p. 55); they included the language used by the participants in order to stay close to the data and to stay close to the meanings of the participants. During initial coding, I analyzed each questionnaire item one at a time. For example, I initially coded all 34 responses to questionnaire item number one, and then proceeded to initially code all 34 responses to item number two. Analyzing all responses (n=34) to one questionnaire item, allowed me to compare “data to data, data to codes, and codes to codes” (Charmaz, 2006, p. 82).

The second phase of questionnaire data analysis involved a grounded theory method called “focused coding” (Charmaz, 2006, p. 57) I used focused coding to synthesize the initial codes. Broader categories emerged to “condense data and provide a handle on them” (Charmaz, 2006, p. 59). For example, the initial code, “observation only” was merged with other initial codes (e.g., observation and inference, observation and experiments, observation and proof/facts, etc.) to create a broader category called “observation,” indicative of responses that disagreed with the statement “Science is based on beliefs,” and used the common term observation in the counter response. I continued to compare data to data, data to codes, codes to codes, categories to data, categories to codes, and categories to categories to check for consistency.

The third phase of questionnaire data analysis involved a grounded theory method called “theoretical coding” (Charmaz, 2006, p. 63). Theoretical coding derives connections between

focused codes, moving the analytical process toward a theoretical direction, and in my case, to develop new theory to then test, during subsequent teacher-research.

The NOS questionnaire findings were reported in several phases. Data from each questionnaire item were presented in two tables and follow-up paragraphs. The first table organized student responses to a questionnaire item into initial and focused codes. Student markers in the first table provided an example of a student constructed response related to each code and category. A second table condensed data further, providing a quantitative summary of the qualitative data. A paragraph(s) followed the two tables, summarizing results.

Extant and Extinct Skull Performance Tasks

Introduction.

This section organized the methods around the extant and extinct skull performance tasks. I discussed my methods by sharing: a) the purpose, b) the construction, c) administration, d) data collection, and e) data analysis of the performance tasks. Last, I addressed validity evidence.

Purpose of performance tasks.

The purpose of the extant and extinct skull student presentations (performance tasks) served both to drive and assess learning. These performance tasks drove learning because they established a clear challenge to students—to reconstruct the life histories of organisms based on the observation and inference of skull characters and to be presented with justification to their peer audience. The higher-level and authentic nature of the performance tasks required considerate time and thorough inquiry, so a sequence of carefully crafted learning experiences aligned to the final performance tasks, was developed. These learning experiences chunked learning into manageable learning pieces to ready students for the final performance challenge.

The performance tasks also drove learning as they engendered motivation to learn due to their authentic nature (apprenticeships in paleoanthropology) and relevance to students (skulls provided novel interest).

The extant and extinct skull presentations also served assess students--to reveal the knowledge, understanding, and skills of students to approximate the work of paleoanthropologists. Last, the two skull presentations created an environment conducive to “teachable moments”, ripe opportunities to reinforce ideas or introduce new ones. These teachable moments were also documented.

Last the extant and extinct skull presentations informed three of my research questions: a) What student abilities of inquiry are demonstrated as students apprentice as paleoanthropologists?, b) How do my conceptions of teaching and learning of human evolution change during the study as I engage in teacher research?, and c) How should the curriculum intervention be modified based on teacher and student data sources?

Construction of performance tasks.

Considering backwards design.

The extant and extinct skull presentation tasks were developed based on the design considerations and criteria of Backwards Design (Wiggins & McTighe, 1998). These considerations included: opportunities of authentic, discipline-based work, enduring ideas, uncoverage, engagement, mature understanding, and national, state, and local learning standards. Below, I explained how the skull presentations met the criteria of Backwards Design.

The skull presentation performance tasks provided opportunities for *authentic, discipline-based work*; like paleoanthropologists, students shared claims about observed skulls, basing these claims on evidence, and presenting such claims to others for critique. Enduring ideas of

science permeated these presentations because of the emphasis essential practices of science-- basing claims on evidence (or in other words basing inference on observation), and on essential practices of paleoanthropology--reconstructing events of the past based on indirect evidence and comparisons to knowns. *Uncoverage* was met via these performance tasks because students were challenged to *do* and *experience* mammology/paleoanthropology in concrete rather than abstract, empty, and superficial ways. Also consistent with *uncoverage*, depth of learning transpired as students explicitly practiced central observation and inference skills of science, and breadth of learning transpired as these skills were extended and connected to difference settings (both extant and extinct).

Mature understandings, defined as demonstrating “connectedness, sense-making, application, and justification” (Smith & Siegel, 2004, p. 563), were approached during the skull presentations. The performance tasks required students to make *connections* from what they had learned during previous learning experiences. During the extant skull presentations, students were asked to *apply* knowledge and experience from the human and gorilla skull learning experiences to interpret an extant skull of choice. During the extinct skull presentations, students were asked to *apply* knowledge and experience from the extant skull learning experiences and performance task. Understanding was also encouraged because students made *sense* of skull characters to tell the important stories of the organism, with an emphasis on *justifying* claims (logical inferences based on observation were required). Last, contextualizing the learning environment through paleoanthropology and using 3-D skulls as a centerpiece for inquiry was meant to promote *engagement*.

The skull presentation performance tasks aligned to national, local, and state curriculum and content standards. Most importantly the skull presentations required learners to grapple with

unifying concepts and processes of science as identified in the National Science Education Standards (NRC, 1996) and listed below. Those incorporated in the skulls Performance tasks are included all components except for “equilibrium”.

- Systems, order, and organization
- Evidence, models and explanation
- Constancy, change and measurement
- Evolution and equilibrium
- Form and function (NRC, 1996, p. 115).

More specifically to the unifying concepts of evidence, models, explanation and measurement above, the skulls performance tasks integrated abilities and understandings of inquiry shown in the Table 3.15 below (NRC, 1996, p. 143).

Table 3.15 <i>Inquiry Standards Integral to the Extant and Extinct Skull Presentations</i>	
Abilities Necessary to Do Scientific Inquiry	Understandings about Scientific Inquiry (highlighted in grey)
• Identify questions that can be answered through scientific investigation.	• Different kinds of questions suggest different kinds of scientific investigations.
• Design and conduct scientific investigation	• Current scientific knowledge and understandings guide scientific investigations.
• Use appropriate tools and techniques to gather, analyze, and interpret data.	
• Develop descriptions, explanations, predictions, and models using evidence.	
• Think critically and logically to make the relationships between evidence and explanation.	• Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.
• Recognize and analyze alternative explanations and predictions.	• Science advances through legitimate skepticism.
• Communicate scientific procedure and explanations.	• Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods for procedures for investigation, or develop new techniques to improve the collection of data.

Some content standards complimentary to the skulls performance tasks were more implicit, yet listed below in Table 3.16.

Table 3.16

Content-oriented Standards Addressed in the Skull Performance Tasks

Content Addressed	Standard and Reference
Skeletal System	“Students will explain that cells are organized into tissues, tissues into organs, organs into systems, and systems into organisms” (GPS).
	“Students will explain the overall purpose of major organ systems in the human body (i.e. digestion, respiration, reproduction, circulation, excretion, movement, control, and coordination, and for protection from disease)” (GPS).
	Students will understand that “The human organism has systems for digestion, respiration, reproduction, circulation, excretion, movement, control and coordination, and for protection from disease. These systems interact with one another (NRC, p. 156).
	“Students should know that like other animals, human beings have body systems for obtaining and providing energy, defense, reproduction, and the coordination of body functions (AAAS, p. 129).
Feeding Roles/Relationships	“Students will demonstrate in a food web that matter is transferred from one organism to another and can recycle between organisms and their environments” (GPS).
	Students will understand that “Populations of organisms can be categorized by the function they serve in an ecosystem...” (NRC, p. 157).
	“Students should know that animals and plants have a great variety of body plans and internal structures that contribute to their being able to find food and reproduce (AAAS, p. 104).
	“Students should know that two types of organisms may interact with one another in several ways: They may be in a producer/consumer, predator/prey, or parasite/host relationship...” (AAAS, p. 117).
Diversity of Living Things	Students will “investigate the diversity of living organisms and how they can be compared scientifically (demonstrate the process for the development of a dichotomous key)” (GPS).
	Students will “examine the evolution of living organisms through inherited characteristics that promote survival of organisms and the survival of successive generations of their offspring”... Students will “explain that physical characteristics of organisms have changed over successive generations” and “trace evidence that the fossil record found in sedimentary rock provides evidence for the long history of changing life forms” (GPS).
	Students will understand that “Millions of species of animals, plants and microorganisms are alive today. Although different species might look dissimilar, the unity among organisms becomes apparent from an analysis of internal structures, the similarity of their chemical processes, and the evidence of common ancestry” (NRC, p. 158).
	Students should understand that “Biological evolution accounts for the diversity of species developed through gradual processes over many generations. Species acquire many of their unique characteristics through biological adaptation, which involves the selection of naturally occurring variations in populations. Biological adaptations include changes in structures, behaviors, or physiology that enhance survival and reproductive success in a particular environment” (NRC, 1996, p. 158).
	Students should understand that “Extinction of a species occurs when the environment changes and the adaptive characteristics of a species are insufficient to allow its survival. Fossils indicate that many organisms that lived long ago are extinct. Extinction of species is common; most of the species that have lived on earth no longer exist” (NRC, p. 158).
	“Students should know that similarities among organisms are found in internal anatomical features, which can be used to infer the degree of relatedness among organisms. In classifying organisms, biologists consider details of internal and external structures to be more important than behavior or general appearance” (AAAS, p. 104).
	“Students should know that fossils can be compared to one another and to living organisms according to their similarities and differences. Some organisms that lived long ago are similar to existing organisms, but some are quite different” (AAAS, p. 123). Note that this is a standard for grades three through five.
	“Students should know that small differences between parents and offspring can accumulate (through selective breeding) in successive generations so that descendants are very different from their ancestors” (AAAS, p. 124).
	“Students should know that individual organisms with certain traits are more likely than others to survive and have offspring. Changes in environmental conditions can affect the survival of individual organisms and entire species” (AAAS, p. 124).
	“Students should know that many thousands of layers of sedimentary rock provide evidence for the long history of the earth and for the long history of changing life forms whose remains are found in the rocks. More recently deposited rock layers are more likely to contain fossils resembling existing species” (AAAS, p. 124).

This section explained how the skull presentation tasks qualified as a pedagogical example of Backwards Design. The next section explained the data collection methods for the skulls presentation performance tasks.

Administration of performance tasks.

Each team of students divided the observations and inferences listed on their data charts (Figure 3.10) presenting that portion of data. One presenter could not hide behind the other, as each had an equal amount of data to present. Student groups were given ten minutes to practice their presentation before the symposium commenced. The sequence of presentations was determined by willing volunteers. I reminded students pre-presentation to use the terms “observation” and “inference” rather than terms like “I see” or “I believe”. I encouraged them to make comparisons of their skull to others in the class, and to make sure their inferences were based on their observations.

Students also participated while in the audience—in order to promote a similar climate of actual scientific symposia. Students were instructed to hold any comments or questions until after each presentation. They were instructed to record any findings they considered interesting, or any questions that arose during the presentations. Last, they were informed of the question and answer session to transpire post-presentation. Their questions/comments should be respectful and constructive if contrary to presenter ideas. Such dialogue and interaction during assessment was encouraged because “a spontaneous question-and-answer session after a speaker’s polished presentation often reveals more about that person’s understanding than the talk itself” (Wiggins & McTighe, 1998, p. 86). I used time between presentations for “teachable moments”, to help students make connections to prior knowledge or introduce new ideas. Teachable moments were recorded at the end of this data section.

Data collection of performance tasks.

Data from the extant and extinct skull performance tasks were collected in two ways. Recording all presentations through video served as one data collection method. The transcripts from these recordings then served as the rough data for inductive analysis. The other method of data collection utilized a rubric (generated from insights rendered from inductive analysis), which served as a second tool and layer of quantitative data collection and data analysis.

Rubric construction.

Developing a rubric common to the extant and extinct skull performance tasks (Figure 3.17) occurred in three phases. The first phase rendered a crude initial rubric; the graphic organizer (Figure 3.10) students used to record their skull observations and inferences served as an initial rubric to frame the expectations of the presentations. The students used this graphic organizer as a reference during their presentations, and I used it as a checklist to make sure students were thorough in their skull descriptions. The early phase of this rubric was useful in organizing content, but limited in its ability to measure knowledge and skills on a continuum.

The second phase of rubric construction occurred after coding transcripts of the presentations, which produced themes of student learning and experience that transpired. These themes were used to create a second scoring rubric more sensitive to various facets of learning and ability and included five domains: a) student use and application of the scientific terms “observation” and “inference”, b) student ability to engage in the practice of comparative anatomy, c) student ability to create logical inferences based on observations (justify claims based on evidence), d) student use and application of scientific terminology (e.g., osteological terminology) and 5) student command of presentation skills.

The rubric assessed students along a novice-expert continuum as suggested by Wiggins and McTighe (1998) in making conceptual development and degrees of sophistication visible. Each domain was separated into five possible levels of performance, represented numerically between the numbers 1 and 5. For example, a student could obtain a score from 1-5 in the domain of using the specific terms “observation” and “inference” in their speech--a score of 1 indicating little to no use of the terms, and a score of 5 indicating full use of the terms. Percentages for each domain were determined by multiplying the domain scores with weighted numbers (higher weighted numbers signifying greater/lesser degrees of importance for that domain) and then adding these derivatives. Adding the percentage scores from each domain produced a total percentage score.

The third phase of rubric construction occurred after scoring all student presentations one time, rendering data then useful for improving the rubric and adding more specifics. This final version of the rubric contained numerical benchmarks or qualifiers for each degree of sophistication within a domain (see the underlined ranges in the rubric). For instance, after initially scoring all presentations, presentation groups used osteological terminology between four and twelve times. This range of 4-12 was used to determine the incremental ranges underlined within the osteological domain. Adding these specific quantitative markers made the scoring process more transparent, objective, and concrete.

Presentation Identifier:							
	1	2	3	4	5	Domain Score	Domain % score
Use of the terms “Observation” and “Inference”	Little or no use <u>0-1</u>	Minimal use <u>2-4</u>	Moderate use <u>5-7</u>	Consistent use <u>8-10</u>	Full use <u>> 10</u>		X 5 = ——
References to comparative anatomy	Little or no distinction <u>0-1</u>	Minimal distinction <u>2-3</u>	Moderate distinction <u>4</u>	Consistent distinction <u>5</u>	Full distinction <u>≥5</u>		X 5 = ——
Logical inferences based on observations	Inferences not logical/based on observations <u>Four inferences were not logical...</u>	Inferences minimally logical/based on observations <u>Three inferences were not logical...</u>	Inferences moderately logical and/or based on observations <u>Two inferences were not logical...</u>	Inferences consistently logical/based on observations <u>One inference was not logical...</u>	Inferences fully logical/based on observations <u>All inferences were logical...</u>		X 7 = ——
Use of scientific terminology	Little or no use <u>0-1</u>	Minimal use <u>2-3</u>	Moderate use <u>4-6</u>	Consistent use <u>7-9</u>	Full use <u>>9</u>		X 2 = ——
Level of command of presentation skills (audible voice, flow and clarity of thoughts, eye contact with the audience)	Little to no command	Minimal command	Moderate command	Consistent command	Full command		X 1 = ——
Total percentage score after adding up all domain percentage scores =							

Figure 3.17. Performance Task Rubric. I viewed video of student presentations and used the rubric above to score presentations.

Rubric and data collection.

Although this performance task rubric was developed in three phases, I used the final version (Figure 3.17) for formally collecting and analyzing data in this research study. I viewed all of the presentations (through video recordings), and coded findings on the assessment rubric. Each group performance was evaluated on one copy of the rubric. I viewed all videos a first time, scoring rubrics, and a second time, scoring a second rubric. If there was a discrepancy between the first and second scores, I viewed the video a third time to settle the discrepancy.

Data analysis of performance tasks.

The analysis of student presentation data occurred in two phases. First, I analyzed the transcripts of student presentations through inductive analysis. This process rendered major categories suggesting that students a) used and applied the terms “observation” and “inference”, b) engaged in comparative anatomy, c) generated logical inferences based on observation, and d) applied osteological terminology to describe skull characters, during their presentations. These categories were then used to create a grading rubric to be reapplied to the presentation data for more quantitative analysis. Last, the similarity of the two performance tasks (each used the same rubric) created long-term focus; the extant skull presentations provided fertile practice ground for perfecting skills and reapplying them during the extinct skull presentations. Therefore, the two performance tasks provided data to assess student improvement over time.

Analysis of transcripts of performance tasks.

The transcripts of the extant and extinct skull presentations were analyzed using inductive data analysis methods, namely those described by Charmaz (2006), and based on the precepts of grounded theory. Grounded theory data analysis systematically analyzes data in order to generate theory, rather than to test it. Theory, themes, or categories emerge from data analysis, which then

might be distilled into testable hypotheses for deductive study. Grounded theory is often appropriate to areas of study not yet conducted--not yet framed by pre-existing theory. Applying grounded theory methods was appropriate to analyzing the skulls presentation because this was a nascent area of research; no such data existed in the prior literature to form a hypothesis to test. I was breaking uncharted territory, seeking to illuminate unique student experience.

I coded the skull presentation transcript data for analysis purposes. Coding refers to “categorizing segments of data with a short name that simultaneously summarizes and accounts for each piece of data” (Charmaz, 2006, p. 43). I first used “initial coding” (Charmaz, 2006, p. 47) and then “focused” coding (p. 57) to systematically analyze presentation transcripts. I heeded Charmaz’s advice when initially coding my transcripts. She suggested to a) remain open, b) stay close to the data, c) keep your codes simple and precise, d) construct short codes, e) preserve actions, f) compare data with data, and g) move quickly through the data (p. 49). I considered a line or two of the transcript at once, creating a gerund to reflect action, which “curbs our tendencies to make conceptual leaps and to adopt extant theories *before* we have done the necessary analytic work” (Charmaz, 2006, p. 48). Initial codes remained tentative, and some changed as I proceeded through coding if I generated better fitting language through subsequent coding. I used this initial coding process to eventually generate broader categories and themes that captured the data, but also to identify the gaps in my data.

I engaged in focused coding after the initial coding of my transcript data. Focused coding involved reconsidering all initial codes, condensing the most frequent and significant initial codes to generate broader categories.

Analysis of rubric data.

I analyzed the data from the performance task rubric to measure student improvement between the extant and extinct skull presentations. I analyzed the rubrics to achieve two main data comparisons. The first compared the average total percentage scores between the extant and extinct skull presentations to gain an overall perspective of change over time. The second compared changes made within the five domains measured.

The total percentage scores for a particular rubric were determined through a series of steps: a) determining domain scores for each rubric, b) determining domain percentage scores for each rubric, c) determining a total percentage score for each rubric, and d) completing summarizing statistics using all of the total percentage scores from all rubrics. Domain scores on individual rubrics were determined as follows: while viewing each video, I used tick marks to indicate the number of times a presentation group addressed one of the domains on the presentation rubric. For instance, if a group member said, “We inferred”, I placed one tick mark on the first domain row of the rubric. If this group member compared his/her skull with another skull in the room, I made a tick mark in the third domain row on the rubric. At the summation of a presentation event, I tallied all tick marks in each domain row, and then determined the degree of sophistication in that domain that was exhibited. For instance, if a group made references to comparative anatomy three times, then they were marked as “minimal distinction” on the rubric, receiving a domain score of 2. I circled each domain score at the end of scoring. The domain percentage scores for an individual rubric were determined by multiplying the domain score with weighted numbers on the rubric (higher weighted numbers signifying greater/lesser degrees of importance for that domain). Adding the domain percentages then rendered a total percentage score for a particular rubric. Last, I used all of the total percentage scores from all rubrics to

render mean, median, and mode scores, comparing these statistics between the extant and extinct skull presentation tasks. I compared the total percentage scores to gain an overall perspective of student improvement over time.

I conducted a second analysis to glean more specific data regarding improvement within the domains measured. I wanted to know on average, how did groups change in the number of times they used and applied the terms “observation” and “inference” in their presentations, for instance. I used the total number of tick marks recorded in a domain for this analysis. I used the total number of tick marks as this number was more specific than a domain score, and allowed comparisons to more closely resemble the raw data. I went through all the extant skull presentation data first, looking at the data from each domain, beginning with the first domain dealing with the number of “observation” and “inference” utterances. I determined the average number of times group members uttered “observation” and “inference” and then compared this average with the average number of times groups uttered “observation” and “inference” during the extinct skull presentations. I proceeded to generate these averages for each of the following domains except the one regarding presentation skills. For this domain, I simply tallied the number of groups who demonstrated “little to no command”, “minimal command”, “moderate command”, “consistent command”, and “full command”; the tallied numbers were used for comparison from extant to extinct skull presentations.

Rubric limitations.

The development of this rubric was useful in my research to see what students can do and how students improved in the five domains over time from the extant to the extinct skull presentations. However, a limitation existed because the students were not privy to the final version of the rubric and its feedback. So, my results may have been different (most likely

improved based on research (Wiggins & McTighe, 1998)), had students studied the rubric before their presentations to help set expectations, and after their presentations with given feedback to be considered on a following presentation.

Validity evidence.

This section provided validity evidence for the skulls presentation performance tasks. I discussed face validity, content validity, and reliability. The limitations of these performance tasks were also considered.

Face validity refers to the extent to which an assessment “looks” like what it was trying to assess (Thorndike, 2005, p. 157). Face validity was important to encourage “the voluntary cooperation of the examinees” (p. 157). Sackett, Schmitt, Ellingson, and Kabin (2001) have also explained that “When a test looks appropriate for the performance situation in which examinees will be expected to perform, they tend to react positively...Equally important, perhaps may be the perception that one is fairly treated (p. 315-316). I attempted to achieve face validity with the skull presentation performance tasks through various ways. First, I set clear expectations days before the actual presentation of skulls. Students were verbally challenged (ahead of time) to present their extant/extinct skull to the their peers, giving them ample time to digest and ruminate on the challenge ahead; the expectations of the performance tasks were also made explicit as students were given the first version of the assessment rubric (Figure 3.10) days before the actual performance task. Next, students worked with the assessment rubric through related learning experiences for several class periods prior to the performance tasks. During these learning experiences, I engaged in formative assessment, providing correction and feedback as necessary. And on the day of the presentation tasks, I verbally instructed students to make sure inferences were based on observation, to use the actual terms “observation” and “inference”, to make

comparisons with other skulls, and to demonstrate effective presentation skills such as making eye contact with the audience. Although these domains were verbally emphasized, they were not represented on the first version of the rubric, which detracted from face validity. A revised and improved rubric (Figure 3.11) was developed through my analysis of presentation video data, and served as a more valid tool during data analysis.

Content validity is one of the most important types of validity in regards to designing ones own assessment (versus evaluating an externally prepared achievement test) (Thorndike, 2005). Attaining content validity means that there is strong alignment between the content of the assessment and the learning objectives/standards. Content validity is also ensured if students have had an opportunity to learn those objectives/standards being measured by the assessment. My students had an opportunity to learn the content to be applied in the performance tasks, because several student activities scaffolded the learning process toward the performance assessment. The first three learning experiences of the extant skull and extinct skull learning sequences scaffolded learning toward the performance tasks, making sure students had an opportunity to learn.

Reliability is a measure of how consistently an instrument/test provides the same feedback/results. Reliability is also a measure of the level of error inherent in the instrument/test. Intra-rater reliability was achieved. I viewed all of the presentations through video, coding findings on the assessment rubric. I viewed video recordings completely through a first and a second time. If there was a discrepancy between the first and second scores, I viewed the video a third time to settle the discrepancy.

Extant and Extinct Focus Group Interviews

Introduction.

This section discussed the methods related to the extant and extinct skull focus group interviews. I discussed these methods in the following subsections: a) purpose of focus group interviews, b) description of focus groups, c) focus group interview protocols, d) data collection, e) data analysis, f) validity evidence, and g) limitations.

Purpose of focus group interviews.

The purpose of the focus group interviews was multifaceted. Overall, the focus group interviews were designed to render rich description and input from student-participants, thus informing all of my research questions:

1. What affective outcomes are expressed when students apprentice as paleoanthropologists?
2. What student views of the Nature of Science are communicated as they apprentice as paleoanthropologists?,
3. What student abilities of inquiry are demonstrated as students apprentice as paleoanthropologists?,
4. What student knowledge of hominin evolution is communicated as students apprentice as paleoanthropologists?, and
5. What student understandings of hominin evolution are demonstrated as students apprentice as paleoanthropologists?
6. How do my conceptions of teaching and learning of human evolution change during the study as I engage in teacher research?

7. How should the curriculum intervention be modified based on teacher and student data sources?

Description of focus group composition.

Twenty-four student-participants comprised six pre focus groups. Twenty-five student-participants comprised the seven post focus groups. Focus group participants were chosen through a series of steps. First, I simply asked particular students if they would like to participate after class. I asked a sample of students in order to get a representative sample. I asked a combination of male versus female, Caucasian versus ethnic students, and high-achieving (A, B students) versus low achieving (C, D, F students). Most of these students were able to attend focus groups occurring during my planning time or before or after school. However, several students declined because of extracurricular commitments or because they were not granted permission to leave their connections class (i.e., P.E., art, music) to meet with me during my planning time. This required me to approach other students whose schedules were amenable to the focus group schedule.

This sampling approach was not ideal, because scheduling challenges often determined whether a student could participate. However, the focus group samples resembled the demographics of the classes involved in this study. Focus group participants were represented by fourteen boys and eleven girls, twenty Caucasian and four non-Caucasian students, and eighteen high achieving and six low achieving students.

The method for assembling students was also not ideal, because it was determined by students' schedules rather than student demographics. Also, controlling the composition of focus group pre to post was attempted but not achieved. For instance, student-participants A, B, C, and D met comprised one pre focus group. However, the schedules of student participants A and B,

differed from those of C, and D post focus group interview. Therefore, replication of the original pre focus group did not occur. However, I did try to maintain consistency as much as possible. For instance student-participants A and B were in the same post focus group, while student-participants C and D were in another post focus group. Also, one pre focus group participant was not able to participate in a post focus group interview. And, two student-participants participated in the post focus group interviews, but not in the pre focus group interviews. Table 3.18 summarized the composition of the pre and post focus groups.

Table 3.17 <i>Summary of Focus Group Composition</i>					
Pre focus group (n=24)	n=	Participant	Post focus group (n=25)	n=	Participant
1	4	A,B,C,D	1	4	B, C, H, I
2	2	E, F	2	3	E, F, L
3	6	G, H, I, J, K, L	3	3	K, Y, Z
4	2	M, N	4	4	A, D, M, N
5	5	O, P, Q, R, S	5	4	J, S, P, O
6	5	T, U, V, W, X	6	6	T, U, V, W, X, R
			7	1	G

Focus group interview protocols.

I used semi-structured interview protocols for both the pre and post focus group interviews (Table 3.19 and 3.20). These protocols were semi-structured in an attempt to align my research methods with my theoretical framework, constructivism and social constructivism. So, my interview approach aligned with the epistemological assumption that meaning making occurs when individuals juxtapose new experiences with their existing conceptual frameworks and in collaborative settings. Therefore, my interview protocols a) framed prompts in a language familiar to participants and connected with their prior and working knowledge, b) unpacked student-participants unique meanings rather than try to guide them to predetermined answers I might want to hear, and c) create an environment of collaboration and trust.

Overall, I attempted to frame interview questions to open up conversation rather than pinhole conversation, and I tried to be flexible in allowing student-participants to guide the conversational direction. For instance, I began interview prompts with vague language such as, “What surprised you about...”, “What stood out about...”, “What did you learn about...”, and “What would you still like to learn about...”. I followed these more open-ended prompts, with more direct ones, based on the conversational direction taken by student-participants.

Because of the semi-structured nature of the interview protocols, some focus groups did not respond to all of the focus group prompts. For instance, one post focus group continued to discuss the future of human evolution for more than twenty minutes, so several topics covered in other focus groups were not discussed in this focus group. Furthermore, prompts may have been framed differently from focus group to focus group, and prompts were not given in the same order to every focus group. I, as the teacher researcher, I made on the spot decisions to rephrase prompts or skip a topic based on what the focus-group participants were saying at that time. If I felt as if I was getting similar answers to an interview prompt (i.e., data saturation) by the third or fourth focus group interview, I refrained from asking this prompt during subsequent focus group interviews, choosing to focus on other prompts with potential to elicit novel commentary.

Table 3.18

Pre Focus Group Interview Protocol

	Interview Prompts and their Variations	Purpose of Prompt
1.	- Anything surprised you about learning about your own skull? - What stood out about learning about your own skull?	To open up conversation regarding the human skull learning experience
2.	What did you learn about your skull?	To glean student knowledge and/or understanding gained from the human skull learning experience
3.	- What has surprised you about learning about your extant skull? - Tell me about your experience with working with your extant skull? - What was it like having the extant skulls in the room?	To open up conversation regarding the extant skull learning experiences
4.	- What did you enjoy learning about with the extant skulls? - What can you learn by just observing the skull?	To glean student knowledge and /or understanding gained from the extant skull learning experiences.
5.	What inferences can you make based on your extant skull?	To assess student abilities to relate evidence to explanation
6.	Was there anything that changed your mind after observing your extant skull?	To assess how student views changed because of the extant skull learning experiences
7.	- What is our understanding of these skulls based on? - What was the main scientific skill that you used while looking at the extant skulls? - How did you learn about your extant skull? - Is what we know about these skulls based on beliefs? - What is your understanding of observation and inference at this point? - How would you define observation? - Using your skull, share an observation and related inference.	To assess students knowledge and /or understanding of NOS concepts such as science as empirically based and assess student knowledge and/or understanding of the relationship between observation and inference
8.	- How would you rate the extant skull learning experiences? Thumbs up, thumb in the middle, or thumb down? Why? - Do you think this is useful to students?	To get overall feedback regarding the extant skull learning experiences
9.	- Is there anything else you would like to learn about these extant skulls? - What would you still like to learn about? - What would you like to know about the extinct skulls that we will be learning about?	To glean student motivations regarding future learning
10.	- What stood out to you all about our evolution unit in January? - How would you define evolution? - How would you explain how species change over time? - What are some lessons we did with evolution that really helped you understand the concept? - How long does evolution take? - What is your response to the statement, "Evolution is <i>just</i> a theory"? - What is your response to the statement, "Humans evolved from monkeys"? - What evidence supports evolution? - What misconceptions do students hold about evolution?	To establish prior knowledge of evolutionary theory as "pre" data to the hominin skull learning experiences.
11.	- Should evolution be in a science book? - How do you all deal with what you learn in science and what you learn in church?	To glean how students negotiate the science/religion issue as "pre" data to the hominin skull learning experiences

Table 3.19

Post Focus Group Interview Protocol

	Interview Prompts and their Variations	Purpose of Prompt
1.	• If you just have to talk about the extinct skulls, what comes to mind? • What have you thought about these extinct skulls? • What has been your overall experience with the extinct skulls? • What stands out to you about the extinct skulls? • What has been most interesting about the extinct skulls? • Has there been anything cool learning about these skulls? • Did anything pop up in your mind when you first saw the extinct skulls?	To open up conversation regarding the hominin skull learning experiences
2.	• What have you learned that you did not know before?	To glean student knowledge and/or understanding gained from the hominin skull learning experiences
3.	• What do you think it means to be human? • What does it mean to be a hominid?	To assess students' abilities to engage in current scientific conversation and base claims on evidence
4.	• What are the relationships of the skulls on the table? How might you arrange them in terms of their relationships and in terms of time? • How would you arrange these hominids to show evolutionary relationships? Justification and sense-making • Which hominin is the most recent ancestor to humans and why? • Where did humans come from based on your phylogenetic tree? • Do you have any idea of what might have caused the evolutionary changes represented by your phylogenetic tree?	To assess students' abilities to construct a phylogenetic tree, and explain this tree giving priority to evidence
5.	We looked at this timeline (Figure 3.16). What stood out to you, or what surprised you when taking a look at that?	To assess student abilities to interpret a phylogenetic tree and glean student knowledge and or understanding of hominin evolution
6.	Why do you think there has been this natural selection for bipedalism?	To assess students' abilities to engage in current scientific conversation and base claims on evidence
7.	How would you respond to the statement "Humans came from monkeys"	To collect "post" intervention data
8.	How would you respond to the statement "Evolution is <i>just</i> a theory?"	To collect "post" intervention data
9.	How long does evolution take? How long does evolution take, such as the evolution of <i>Homo ergaster</i> to <i>Homo sapiens</i> .	To collect "post" intervention data
10.	Which skull do you think is the "missing link". Why? Why was Lucy such an important find?	To assess students' abilities to engage in current scientific conversation and base claims on evidence
11.	If you could fast forward a couple of hundred thousands of years, how might humans be different than they are today? How might this human evolutionary change occur?	To assess students' abilities to apply knowledge of natural selection to human evolution
12.	How has this unit on extinct skulls added to your understanding to the nature of science?	To assess how the hominin skull learning experiences

	Can science change? What is our understanding of evolution based on? How would you respond to the statement “Evolution is <i>just</i> a theory?”	enhanced students’ knowledge and/or understanding of the NOS
13.	Has this unit been useful or not useful? Should 7 th graders learn about human evolution?	To open up conversation regarding the science/religion issue
14.	Are there any questions about evolution that you feel are unanswered to you?	To glean areas to improve or add to learning experiences

Data collection during focus group interviews.

I collected data in two ways during the focus group interviews. I recorded the interviews using both a digital audio recorder and a video camera. I placed the digital audio recorder on the table where focus group participants gathered to converse. I used the digital audio recorder to obtain the clearest audio data as possible. I also video recorded the focus group events for several reasons: a) as backup data in case the audio files became corrupted, and b) to gather visual data of students collaborating together, expressing emotion or emphasis, referring to skulls, creating their phylogenies, etc. I did not take any notes during the focus group interviews, as I wanted to be present in the conversation as much as possible, and I did not want focus group participants to feel as if I were grading or analyzing their responses.

Data analysis of focus group interview data.

The data analysis of focus group interview data occurred in a series of tedious, cyclic, systematic steps. I first transcribed digital audio data, adding clarification by viewing video data. Then I analyzed my transcripts through inductive analysis to organize data, and create frameworks of data to make claims regarding cognitive and affective learning outcomes. Methods borrowed from grounded theory, such as line-by-line coding were used to make sure I was systematically looking at my data.

Transcribing digital audio data of focus groups.

As the first part of data analysis, I transcribed all pre and post focus group interview data using the audio recordings only. Listening to audio took out visual input, allowing me to first focus on the specifics of student language. I tapped into the video data to clear up any muffled audio data, or to add important data. For instance, student participants often stated “this one” or “that one” when referring to a skull, or stated “here” or “there” when discussing the placement of a skull within a phylogeny. I used video data to add specific terminology to the student use of pronouns, and bracketed this additional data to represent its indirect place in conversation. The following is an example of how I added clarifying data after transcribing a pronoun:

I was just surprised about how detailed it [extant skull] was. Like its...how detailed it is. And the second is like how much it [extant skull] can tell you about the animal. Like if it's [the extant mammal is] an omnivore and what it [extant mammal] eats and all of that”.

I also deleted redundant language or superfluous chatter that added no meaning. The highlighted text in the following student excerpt represents what I deleted while transcribing:

I was just surprised about how detailed it [extant skull] was. Like its...how detailed it is. And the second is like how much it [extant skull] can tell you about the animal. Like if it's [the extant mammal is] an omnivore and what it [extant mammal] eats and all of that”.

After transcribing the digital audio focus group data, I gained an overall sense of student experience and meaning making, but I needed a more systematic way to organize and summarize my data, so used inductive analysis.

Line by line coding of focus group transcripts.

The second phase of the focus group data analysis applied the inductive analysis approach to the focus group transcripts. Applying the inductive analysis approach to the focus group transcripts was appropriate because:

- a) I needed a systematic way to categorize and summarize this qualitative data, and
- b) my data set was original—the literature review provided no framework for analyzing my data, and inductive analysis allowed me to explore my data to generate meaning, new frameworks, and new theory.

Coding procedures borrowed from grounded theory methods helped me to organize and describe my data, create meaning, and develop frameworks of understanding. I presented these frameworks in tables showing initial codes, focused codes, and examples excerpts (markers) related to these codes.

I began inductive analysis by applying line-by-line, open coding to focus group transcripts (Charmaz, 2006). I started with one of the pre focus group interview transcripts, considering one or two lines of transcript at a time, and then generating an initial descriptive code. I wrote this code in the margin. I followed Charmaz's (2006) suggestions when creating initial codes:

- Remain open
- Stay close to the data
- Keep your codes simple and precise
- Construct short codes
- Preserve actions
- Compare data with data

- Move quickly through the data (p. 49).

As I proceeded through subsequent pre focus group transcripts, I compared data to data and codes to codes, to make sure I was being consistent and systematic.

I worked through each pre focus group transcript as described above. Then, I began to create tables to organize these initial codes, and then subsume these initial codes under broader focused codes, and then subsume focused codes under broader categories. Final tables represented frameworks of student experiences, abilities, knowledge, and understanding, which then were used to make overarching claim.

Once I created the pre focus group frameworks or tables, I began the coding process with post focus group interview data: 1) I looked closely at the transcript data line by line, assigning initial codes, and 2) I then subsumed initial codes under focused codes. Oftentimes, I did not have to create tables from scratch as with the pre focus group interview data. I was able to use tables already created, juxtaposing post focus group interview data with the pre focus group interview data. These tables showed pre to post comparisons (e.g., comparing the frequency of an initial or focused code pre to post). However, the markers or excerpts were from post focus group interview transcripts. For instance, the table created when analyzing pre data regarding student responses to “Humans evolved from monkeys” was used to organize relevant data from the post focus group interviews. Tables helped me to make claims regarding the impact of the extinct skull learning on cognitive and affective learning outcomes. However, some of the post focus group interview data rendered unique experiences, so new frameworks were developed.

I tried to take the most parsimonious approach to coding data, assigning the least amount of initial codes per student response. However, the nature of some student responses required me to double or triple code. Take the following student excerpt:

I absolutely love to think outside of the box, and still have that curious mindset about things. So, I love to think about how this [hominin] could have gone extinct, making more inferences about all the characteristics of the skulls, and thinking about the future. You could just go beyond and beyond and just keep going about all of your ideas about the topic and I just really enjoyed learning about it.

This student excerpt received three initial codes. This student participant used the word “love” twice and the word “enjoyed” once, so I coded this excerpt under the initial code, ““expressing positive emotive language”, which was subsumed under an overall theme of affective outcomes of learning. However, this student also referred to the scientific habits of mind (i.e., science as creative and divergent) that were engendered by learning experiences. Therefore, this excerpt was also initially coded as “creative” and “divergent”, both subsumed under the focused code of “Science as...”, subsumed under the category NOS, subsumed under the overall theme of cognitive learning outcomes.

Assessing the validity of the focus group data.

I attempted to generative trustworthy focus group data through a robust sample size, face and content validity of focus group protocols, and intra- and inter-rater reliability.

First, I tried to include as many student participants as possible ($n = 24$ for pre focus group interviews and $n = 25$ for post focus group interviews). The successful and empirically based studies summarized in my literature review, reported similar sample sizes. For example Smith and Scharmann (2008) worked with 15 participants, Scharmann (1990) worked with 30 participants, and Crawford, Zembal-Saul, and Friedrichsen (2005) worked with 18 participants. I perceived that 25 focus group participants might generate diverse viewpoints as well as allow me to sample student thinking enough toward data saturation.

I was careful in designing interview prompts in order to approach face and content validity. I attempted to approach face validity by framing prompts in the language previously used in our classroom, appropriate to the learning level of students, and designed to open up conversation. Therefore, my focus group interview protocols would have some face validity because they would “look” like what they were trying to assess (Thorndike, 2005, p. 157), encourage “the voluntary cooperation of the examinees” (p. 157), and create an environment of fairness (Sackett, Schmitt, Ellingson, and Kabin, 2001).

I attempted to approach content validity by aligning focus group prompts with the main ideas of the learning experiences, and making sure that student-participants had an opportunity to learn or experience what the focus group protocols were trying to unpack (Thorndike, 2005).

I also tried to achieve intra- and inter-rater reliability as a measure of how consistently the focus group methods were giving similar feedback/results. The initial coding process of focus group transcripts required that I consistently compare data to data and codes to codes. This process culminated in the careful review of each transcript at least two times, sometimes more if discrepancies continued to arise. The process of checking and rechecking my codes for consistency contributed to intra-rate reliability. Also, my major professor read through the frameworks (Tables) that I created, and checked for consistency regarding the assignment of student excerpts to initial codes, focused codes, categories, and themes. This practice contributed to inter-rater reliability.

Limitations of focus group interview data.

Several limitations affected the types of claims I was able to make from the focus group interview data. First, the data analysis of focus group data occurred four years after data collection. The time lapse between data collection and data analysis occurred because of

professional (coursework and assistantship responsibilities) and personal (marriage, illness, and the birth of my two sons) reasons. One downside to the time lapse deals with my ability to recall classroom specifics--to help me as the researcher make connections between student-participants comments during the focus group interviews, and relevant occurrences that may have occurred during instruction. However, one benefit to the time lapse deals with seeing the data from anew and with distance. This may have added more objectivity to the data collection process and more sophisticated interpretation given my additional coursework and readings in qualitative research and science education.

Second, the semi-structured nature of the interview protocol made it more difficult to track individual change pre to post interview. For instance, one pre focus group discussed their views regarding the statement, "Humans evolved from monkeys." However, some of these participants did not comment on this statement post-interview because they talked more about other interview prompts. Therefore, I summarized data in a cumulative sense, and tracked individual student change when possible.

Third, the difficulty in controlling the composition of pre to post focus group members may have imposed other limitations. Controlling pre and post focus group members might have allowed a) for an increased comfort level of students during interviews because of increased familiarity among student-participants b) me as the teacher-researcher to ask specific questions post interview based on the conversational direction set by the pre focus group interviews.

Last, taking on the dual role of teacher and researcher imposed certain tradeoffs. As a teacher, I think that I was able to deliver a strong instructional intervention, appropriate, challenging, and motivational for my students. I was also able to capitalize on my long-term relationship with students, and use this level of trust during interviewing. However, some

student-participants may have been reticent to share their true views because of my closer relationship to them. Because of teaching responsibilities, I was not able to be as efficient as a researcher. For instance, transcribing pre focus group interviews before conducting the post focus group interviews, might have provided insights for creating the post interview protocol. Also, using student work samples during focus groups (e.g., questionnaires, anticipation guides, phylogenies) might have helped students talk about their experiences and what they felt like they had learned because of the instructional intervention. Using these props during interviewing may have also helped me unpack student conceptions. The organizational task of pulling student work samples for focus group participants did not transpire in the context of my other multitasking duties.

Overall, I recognize the limitations of conducting teacher-research. However, I think the unique contributions of privileged and prolonged access to my research situation make up for these limitations.

CHAPTER 4

RESULTS

NOS Pre/Post Questionnaire: Inductive Analysis Results

NOS Questionnaire Findings

The NOS questionnaire findings are presented in Tables 4.1-4.10. Two tables organized and categorized the responses to each questionnaire item. The first table (e.g., Table 4.1) organized and categorized each student's response to the particular questionnaire item in an initial and focused code. The number of student responses on the pre-questionnaire versus the post questionnaire were shown to illustrate any changes in student viewpoints. Example student responses were also shown as "markers," or representative student responses to the categories and codes presented. The second table (e.g., Table 4.2) organized these initial and focused codes into broad categories for further analysis (e.g., Table 4.2). Pre and post data was presented as well as marker student responses. The findings presented in this section informed research question two, six, and seven: What student views of the Nature of Science are communicated as they apprentice as paleoanthropologists, How do my conceptions of teaching and learning of human evolution change during the study as I engage in teacher research, and How should the curriculum intervention be modified based on teacher and student data sources?

Science knowledge is based on beliefs.

Tables 4.1 and 4.2 organized and categorized all NOS pre- and post-questionnaire responses to item number one, "Science knowledge is based on beliefs". I hoped students would recognize the problematic nature of this statement, and change the word "belief" to

“observation”. Further recognition would be given to students who also noted that subjectivities arise in spite of this main tenant of science. Initial codes (e.g., observation and inference) and focused codes (e.g., observation) served as fields for organizing and summarizing data (Table 4.1). Initial and focused codes were further condensed into: (a) absolutist, (b) hybrid (between absolutist and subjective), (c) subjective, and (d), unclear categories (Table 4.2).

Most students (64.7%) expressed an absolutist view—science knowledge is based on observation, facts, proof, evidence, or experiments—pre NOS intervention. These absolutist views persisted post intervention (67.6%). A higher level of absolutist views were not surprising given that the NOS intervention was focused on science as empirical, and that “belief” was defined in the questionnaire as related to religion, opinion, and faith. What was surprising was that individual student views changed little due to the intervention. A second surprise surfaced with an examination of those views categorized as “hybrid”. These students agreed that science was based on observation, but added that it was also based on belief, relating belief to scientific terms such as inference, theory, and hypothesis. For example, one student explained,

I think that most of science is based on facts, but some of it is based on beliefs. A example of facts is that the existence of dinosaurs was proven, using bones. An example of beliefs is the Big Bang Theory.

This student may be implying that a scientific theory is not substantiated by evidence, and is just a guess. Likewise, other students conflating inference, hypothesis, and theory with belief, may perceive these constructs as flimsy—disconnected from observation.

Science knowledge is formed only through observation.

Tables 4.3 and 4.4 organized and categorized the NOS questionnaire results to the prompt

“Science knowledge is formed only through observation”. I hoped students would recognize the problematic aspect of this statement. Even though observation is quintessential to scientific knowledge, it forms the basis of inferences, hypotheses, theories, and explanations, which extends scientific knowledge.

Table 4.1 <i>Student Responses to, “Science Knowledge is Based on Beliefs”</i> (<i>n</i> = 34)				
Focus d Code	Initial Code	# p r e	# p o s t	Marker(s)
Unclear		3	0	A. I think it is true because to me beliefs can be a lot of things and these definitions mostly answer what beliefs mean. B. ...a belief is something believed with confidence, faith, or trust but it is not really an opinion. It can't really be an opinion if you believe in something that could your could not be proved.
Belief	But not religious	1	2	I chose I don't know because it is based on beliefs, but not really on religious beliefs. A belief in science is something believed with confidence, faith, and trust.
	In self	1	0	I picked “B” because when a scientist conducts an experiment he needs to have belief in his or her own work. Science knowledge is partly based on belief.
	Contemplating “proof”	1	1	I believe that this statement is true because of the mistakes made and ability to “prove” things are true. Several mistakes and misbeliefs are made in science, such as the thought that the world is flat. People used to believe that the world was flat, and claimed that it was true. Now we know that is was only a mistaken belief. Also, scientists are still debating if science can be proven, if not, than all science is a series of beliefs.
Not beliefs	only	2	2	Scientists believe in different beliefs. Science is not based on belief.
	But subjectivity arises	0	2	I chose sort of true, because some scientists could be religious or just have their own opinion and could put that in their science and we can't be 100% sure because we don't know what is going on in someone's head. To make this statement 100% true, it would need to say: science should not be based on beliefs but sometimes scientists could base it on beliefs.
Observation	only	0	3	When you think about it, everything is an observation. Whether you observe the test strip, the planets in our solar system, or an animal (such as a gorilla) at the zoo.
	And experiments	3	2	Science is not based on belief. It is based on trial and error, and doing experiments and observations. Science is not based on belief.
	And proof/facts	0	2	I chose this answer because science is based on observation because you have to have proof. You have to put your opinions aside and observe what you know and not what you believe in. Science knowledge is based on observation and facts.
	And inference	1	2	Science isn't based on beliefs, it's observations and inferences because one person's beliefs may be different from another person's beliefs.
	And belief	0	2	I chose sort of true because even though science is mostly formed through observation it is also formed on the scientist's beliefs.
Experiments		1	0	Science knowledge is based on the results of an experiment that has been conducted many times.
Evidence		2	1	Science knowledge is based on evidence to support a theory or statement.
Proof		1	0	Science knowledge is not based on beliefs because if you cannot prove something, then you cannot be 100% sure that it is there. One example is God. Most people believe that He is there, but we cannot do an experiment to prove it.
Facts	only	0	1	Science is based on facts. Change the question to “scientists have beliefs”.
	And experiments	0	2	Science is based off facts and data received from experiments. Science knowledge is not based on beliefs whatsoever. You could say, science knowledge is based on facts.
	And research	0	1	Science is answered through facts and research, not beliefs.

That inform hypotheses	0	1	Science is based on facts. A hypothesis may be based on a fact until proven with facts. This makes this statement mostly false. Science knowledge is based on proven facts.
That are verified	4	1	Science is based on facts that have double and triple checked.
With subjectivity	5	2	Some science questions come from curiosity and beliefs because scientists wonder about things and conduct experiments. Other things come from facts. Also, since things are never proven, you have to believe they are true.
And belief	1	2	The statement above is kind of true and false because science is based on fact and opinion. For example, science is based on mostly facts.
And belief conflated with inference, hypothesis, and/or theory	8	5	I think that most of science is based on facts, but some of it is based on beliefs. An example of facts is that the existence of dinosaurs was proven, using bones. An example of beliefs is the Big Bang Theory.

Table 4.2

Percentages of Student Responses to “Science Knowledge is Based on Beliefs”

Category	Pre %	Post %	Marker
Absolutist	64.7	67.6	Science is based on facts that have been double and triple checked.
Hybrid	17.6	23.5	I chose sort of true because even though science is mostly formed through observation it is also formed on the scientist's beliefs.
Subjective	2.9	2.9	I believe that this statement is true because of the mistakes made and ability to “prove” things are true. Several mistakes and misbeliefs are made in science, such as the thought that the world is flat. People used to believe that the world was flat, and claimed that it was true. Now we know that is was only a mistaken belief. Also, scientists are still debating if science can be proven, if not, than all science is a series of beliefs.
Unclear	14.7	5.9	I think it is true because to me beliefs can be a lot of things and these definitions mostly answer what beliefs mean.

Table 4.3 showed how student responses were assigned to an initial and focused code, while Table 4.4 condensed these codes into the following categories: (a) absolutist: observation only, (b) observation and “other ways”, (c) observation and belief, and (d) not sure.

Absolutist views of scientific knowledge construction increased pre to post intervention from 23.5% to 41.11%. These students agreed 100%, that science knowledge is formed only through observation. Therefore, misconceptions of the epistemology of science may have increased due to the NOS intervention.

Table 4.3
Student responses to, “Science Knowledge is Formed Only Through Observation”
 (n = 34)

Focused Code	Initial Code	# pre	# post	Marker
Not sure		2	0	Science knowledge may only be formed through observation but I am not really sure and don't completely understand the question. I am not sure.
Observation		8	14	If you think about it, everything is an observation. Whether you observe the test strip, the planets in our solar system, or an animal (such as a gorilla) at the zoo.
Observations	and patterns	1	0	Science knowledge is mostly formed through observations. Also, I believe some comes through patterns and other observations. The patterns and other observations make a prediction.
	and tests or experiment	2	7	I picked E because you can observe science knowledge, but you can also feel and test for knowledge. Science knowledge is formed by you senses, observations, and running tests.
	and teachers	0	1	Science knowledge is formed through observation and taught to you.
	and research	0	2	You may have to do research. Science is formed through observation and previous knowledge.
	and inferences	4	1	Most of science we observe, but other idea we inference about them like what color dinosaurs are.
	inferences and data	1	0	You receive knowledge from data and inferences. Most of the time you do get knowledge from observations. Science knowledge can be formed through observations, inferences, or data.
	inferences and research	6	0	You have to research not just observe what's going on or you can't always know what is going on. Science knowledge is formed by using observation, inferences, and research.
	inferences and imagination	1	2	The statement is sort of true and false because can't observe everything that happened in the pass. For example, scientist have to put their imagination in and how the universe was formed.
	inferences and tests or experiments	2	0	You need to make inferences and you need to tests those inferences to know science knowledge you need to make inferences for your observations. Science knowledge is formed through observations, inferences, and tests.
	inferences and hypothese	1	0	You have to make inferences or hypothesize.
	hypothese and theories	1	3	I believe that this statement is sort of true because scientists form hypothese and theories oftentimes without observing what actually happens in the experiment or world, yet they do. I would change the statement to be “Science knowledge is formed with and without observation.”
	and other ways	5	3	A. To form science knowledge, you do use observation skills. Though it is not the only way. You also use experiments, data, and other ways to form knowledge. Science knowledge is formed in many ways. B. It is true that science is made up of observations, but there are other parts of science. For example, there has to be a question, hypothesis, etc. If I wanted to change this statement, to make it true, I would change it to “Science knowledge is formed mostly through observation.”

	and belief	0	1	I chose sort of true because even though science is mostly formed through observation it is also formed on the scientists' belief.
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Table 4.4
Percentages of Student Responses to “Science Knowledge is Formed Only Through Observation”
 (n=34)

Category	Pretest %	Posttest %	Marker
Absolutist: Observation only	23.5	41.1	If you think about it, everything is an observation. Whether you observe the test strip, the planets in our solar system, or an animal (such as a gorilla) at the zoo.
Observation and “other ways”	70.6	55.9	To form science knowledge, you do use observation skills. Though it is not the only way. You also use experiments, data, and other ways to form knowledge. Science knowledge is formed in many ways.
Observation and belief	0	2.9	I chose sort of true because even though science is mostly formed through observation it is also formed on the scientists' belief.
Not sure	5.9	0	Science knowledge may only be formed through observation but I am not really sure and don't completely understand the question. I am not sure.

Science can answer all questions.

Tables 4.5 and 4.6 organized and categorized the NOS questionnaire results to the prompt “Science can answer all questions”. I hoped students would recognize the problematic aspect of this statement; science is limited in answering questions dealing with the natural world. Table 4.5 showed how student responses were assigned to an initial and focused code, while Table 4.6 condensed these codes into the following categories: (a) natural world, (b) testable, (c), no questions, (d) most questions, and (e) tentative.

Most students demonstrated normative views pre-intervention; 91% of students expressed that science answers most questions, excluding those questions that deal with religious, metaphysical, or supernatural content. I was pleased that most of my students held such views prior to the NOS intervention, possibly indicative of our previous conversations about the limitations of science in our class. I was also pleased that they improved their statements post-

intervention; students also clarified that science is limited to questions dealing with the natural world. No students used “natural world” in the pre-intervention data; however, 41.2% used this terminology in the post-questionnaire. Future research would have to be conducted in order to assess students’ understanding of “natural world”. Such assessments might require students to recognize, eliminate, or construct scientific questions based on this criterion.

Table 4.5 <i>Student Responses to, “Science Can Answer All Questions”</i> (<i>n</i> = 34)				
Category		# pre	# post	Marker
Science can answer questions concerning the natural world and excluding	Questions derived from other disciplines	0	1	Science can only answer scientific questions and not math, social studies, or language arts questions. For example, who is Martin Luther King Jr. cannot be answered in science. Science can answer all natural questions.
	Religious and/or metaphysical questions	0	12	Science cannot answer questions about religion, the supernatural world, etc. Science can answer questions about the natural world.
	Religious and/or metaphysical questions but including those that are testable	0	1	Science can only answer questions testable or of the natural world. Science cannot answer questions about religion and the supernatural. For example, scientists cannot explain how the universe was created. Science can answer only questions about the natural world, but not the supernatural like religion.
Science can answer testable questions that are not related to religion		0	3	Science cannot answer questions about religion, or things that are not testable. Science cannot answer all questions.
Science can answer no questions		1	0	In science, no question can ever be “proven”. There is no way to know that the result is the correct answer. Also, in some cases, there can’t even be an experiment composed because the question is so great. Science can never be proven to answer a question correctly.
Science can answer most questions		1	1	Science can only answer some questions. It can’t answer all.
Science can answer most questions excluding	metaphysical questions	6	1	Science can answer a lot of questions but not all. It can’t answer how the universe was created, or the meaning of life, etc. Science can answer lots of questions but not all.
	Religious questions	8	3	Science does not know how to answer beliefs in religion or some other aspects because there is no proof. People believe religions through faith, not logic. Science can answer most questions through tests and trials.
	Metaphysical and religious questions	12	10	Science can answer a lot of questions, but not all. For example, they can’t prove how the universe was born, and they can’t answer whether or not there is a God. Science cannot answer all questions.

	Those derived from other disciplines	1	1	Science answers a lot of questions, but not exactly all questions. For example, if a question was $4 + 7$ then that would be a math question. Also, if there is a question of when was the cold war, that would be social studies. Science can answer a lot of questions, but not all questions.
	Those related to past events	3	1	Science can answer most questions. What color were T-rexes, this cannot be answered.
Science can answer most questions but some “answers” remain tentative		2	0	Science cannot answer every single question on Earth, they may not have enough evidence. For example they have THEORIES about the Earth’s formation (The Big Bang Theory), but don’t know for sure if that’s correct. Science can answer most questions.

Table 4.6 <i>Percentages of Student Responses to “Science Can Answer All Questions” (n=34)</i>			
Category	Pretest %	Posttest %	Marker
Natural world	0	41.2	Science cannot answer questions about religion, the supernatural world, etc. Science can answer questions about the natural world.
Testable	0	8.8	Science cannot answer questions about religion, or things that are not testable. Science cannot answer all questions.
No questions	2.9	0	In science, no question can ever be “proven”. There is no way to know that the result is the correct answer. Also, in some cases, there can’t even be an experiment composed because the question is so great. Science can never be proven to answer a question correctly.
Most questions	91.2	50	Science can answer a lot of questions but not all. It can’t answer how the universe was created, or the meaning of life, etc. Science can answer lots of questions but not all.
Tentative	5.9	0	Science cannot answer every single question on Earth, they may not have enough evidence. For example they have THEORIES about the Earth’s formation (The Big Bang Theory), but don’t know for sure if that’s correct. Science can answer most questions.

Data collected in science are collected with honesty, clarity, and accuracy.

Tables 4.7 and 4.8 organized and categorized the NOS questionnaire results to the prompt “Data collected in science are collected with honesty, clarity, and accuracy”. I hoped students would agree that collecting data with honesty, clarity, and accuracy is a standard of science, yet because humans conduct science, the standard is sometimes not achieved; some scientists make

mistakes during data collection or are fraudulent. Table 4.7 showed how student responses were assigned to initial and focused codes, while Table 4.8 condensed these codes into the following categories: (a) natural world, (b) testable, (c), no questions, (d) most questions, and (e) tentative.

Twenty nine percent of the participants agreed 100% with this questionnaire statement pre-intervention. Unfortunately, this absolutist view increased to fifty-three percent post-intervention. These students expressed that science must be collected with honesty, clarity, and accuracy in order to obtain validity and trustworthiness. Although collecting data with honesty, clarity, and accuracy is a standard of scientific practice, student missed the nuance that this standard is sometimes not reached; humans conduct science, subjectivities influence the data collection process, scientific knowledge can change over time due to improved methods, and some scientists fabricate data.

Table 4.7 <i>Student Responses to, “Data Collected in Science are Collected with Honesty, Clarity, and Accuracy”</i> (<i>n</i> = 34)				
Category		# pre	# post	Marker
I don’t know		1	0	I haven’t ever heard anyone talk about that.
100% Agreement		10	17	I agree with this statement 100% b/c if the data isn’t collected w/ honesty, clarity, & accuracy the data will not be valid and cannot be trusted.
Agreement with	Human bias	3	2	Data is collected with as much honesty, clarity, and accuracy as possible, but everyone is human. Emotions and feelings can get in the way.
	Mistakes/lack of clarity	15	10	Scientists try to be objective, but sometimes measurements and observations get messed up or slighted.
	Tentativeness	5	4	I think it its sort of true, because most data collected is with honesty, clarity and accuracy. Not all data is collected with honesty, clarity, or accuracy, because something can change in time.
	Accountability	0	1	Data is meant to be answered with honesty, clarity, and accuracy, and those who don’t will be caught by other scientists to make it accurate, clarified, and honest.

Table 4.8 <i>Percentages of student responses to “Data collected in science are collected with honesty, clarity, and accuracy”</i> (n=34)			
Category	Pretest	Posttest	Marker
Absolutist	29.4	52.9	I agree with this statement 100% b/c if the data isn't collected w/ honesty, clarity, & accuracy the data will not be valid and cannot be trusted.
Tentative/Subjective/ Malpractice	67.6	47.1	• I think it its sort of true, because most data collected is with honesty, clarity and accuracy. Not all data is collected with honesty, clarity, or accuracy, because something can change in time. - -Tentative • Data is collected with as much honesty, clarity, and accuracy as possible, but everyone is human. Emotions and feelings can get in the way. -- Subjective • Scientists try to be objective, but sometimes measurements and observations get messed up or slighted. --Malpractice
Don't know	2.9	0	I haven't ever heard anyone talk about that.

Science must follow certain rules.

Tables 4.9 and 4.10 organized and categorized the NOS questionnaire results to the prompt “Science must follow certain rules”. I hoped students would generally agree with this statement, explaining the discipline of science has standards of practice, such as basing claims on evidence and collecting data with honesty, accuracy, and clarity. Student data suggests that students may have made both positive and negative conceptual movement. From a positive standpoint, more students post intervention (21 student-participants versus 6) recognized that scientists must strive to be honest, accurate, and clear. However, less students post intervention explained that science does not follow rules in terms of a strict scientific method, and that methods are dependent on the nature of individual inquiries. These results might be explained due to different interpretations of the word “rule”. Pre intervention, students may have perceived this term to mean a strict scientific method, and post intervention, student-participants may have perceived this term to refer to standards of practice.

Table 4.9
Student Responses to the Prompt, “Science Must Follow Certain Rules”
 (n = 34)

Category		# pre	# post	Marker
I don't know		3	1	I picked “C” because I don't know whether or not they have to follow certain rules.
100% Agreement		0	3	Science has to follow rules.
	Toward valid/accurate data	6	21	A. You have to follow rules to get valid data, such as you can't lie. B. For science, you must follow rules, like: collecting data with honesty, clarity, and accuracy.
	Such as collecting data	0	1	There is a certain set of rules that applies to all science. You need to make observations and inferences, and you need to collect data.
	Toward safety	1	1	If rules aren't followed, safety is unstable.
	Toward replicability	1	0	Otherwise any rules could be used, and everybody would do it differently.
	i.e. scientific method		2	In science, you must experiment to answer questions, come up with a hypothesis, have clear procedures, and a conclusion.
Agreement	but bad science happens	1	0	Not all scientists follow all the rules. All data should be collected with honesty, clarity, and accuracy and sometimes scientist lie or aren't clear enough.
	but the scientific method is limited	5	1	Science sometimes follows certain rules, like the scientific method, but it does not always. Sometimes there is no method. Science can follow certain rules.
	but rules are dependent on individual inquiries.	12	2	Science does follow rules but some rules don't apply to certain experiments. Science must follow certain rules for certain experiments or researches.
Guidelines instead of rules		3	2	There are no certain ‘rules’, but there are guidelines. For example, data must support the conclusion. It is important to follow rules, but it is not a requirement.
No rules		2	0	There really are no rules in science. There is not a rule book that tells you step by step what to do.

Table 4.10
Percentages of Student Responses to “Science Must Follow Certain Rules”
 (n=34)

Absolutist		Malpractice/?		Guidelines		No rules	
Pre %	Post %	Pre %	Post %	Pre %	Post %	Pre %	Post %
23.5	82.4	52.9	8.8	8.8	5.9	5.9	0

Discussion of Pre/Post NOS Questionnaire Results

The purpose of the 3- hour NOS scaffolding unit was to: (a) enhance student notions of science as empirically based and (b) concerned with studying the natural world, and (c) indirectly challenge student notions of a science-religion dichotomy. I perceived that achieving such instructional goals would help students enter later conversations regarding human evolution. An analysis of the pre- and post-questionnaire data revealed several emergent themes, rendering implications for both pedagogical and research improvements. The emergent themes included: (a) absolutist views of science, (b) conflating belief with inference, hypothesis, and theory, and (c) science and the natural, *present* world.

Absolutist views of science.

According to the pre-questionnaire, students brought absolutist views of science to the learning experiences; 64.7% of students disagreed absolutely with the statement “Science knowledge is based on beliefs”, 23.4% of students absolutely agreed with the statement that “Science knowledge is formed only through observation”, and 29.4% of the students agreed absolutely with the statement that “Data collected in science are collected with honesty, clarity, and accuracy”. Unfortunately, these extreme views became more predominant after the NOS scaffolding unit with 64.7% increasing to 67.6%, 23.5% increasing to 41.1%, and 29.4% increasing to 52.9%. These results suggested that there was conceptual movement toward notions of science as empirically based, yet at the expense of notions of science as subjective and tentative.

The two NOS learning experiences tailored to the NOS concept of science as empirically based were lesson experiences two (comparing science with football) and four (NOS card sort). Reflecting on these two learning experiences revealed that I may have reinforced absolutist

views of science, not necessarily by directly focusing on observation, but by leaving out the important nuances—observation as theory-laden and tentative. For example, our science-football graphic organizer showed that we decided that one of the rules of science included, “Science knowledge is based on observation”. However, there was no documented conversation regarding how new observations may enhance or change the existing ones. Incorporating an discussion of football and instant replays would have addressed this issue. The science football comparison may enhance student notions that the discipline of science is unique and framed by certain assumptions (as suggested by the results of questionnaire response five). However, it appeared over-simplistic in its ability to encourage critical thinking about particular nature of science concepts in relation to one another.

The NOS card sort did include an oppositional card set dealing with the tentative nature of science, science “can change” versus “cannot change”. This may have provided an opportunity for groups to engage in discussion and learning. However, there was not a card set dealing with the subjective nature of science. So, the NOS card sort provided only brief opportunities for students to grapple with science knowledge as both empirical, yet tentative/subjective. A reexamination of these two learning experiences suggested that observation as empirical, yet tentative and/or subjective must be addressed in tandem. Such a conclusion will require future creative curricular development, as students may confuse tentative/and or subjective with flimsy, which may provide fodder for dismantling evolutionary theory. The benchmarks warned “...it is important not to overdo the ‘science always changes’ theme, since the main body of scientific knowledge is very stable and grows by being corrected slowly and having its boundaries extended gradually (AAAS, 1993, p. 5).

Conflating belief with inference, hypothesis, and theory.

Responses to questionnaire prompt number one, “Science is based on belief” rendered additional considerations for teacher reflective practice. As implied in the previous section, I took note of the amount of absolutist views of science (64.7%) that students brought to the learning experiences. In addition, eight students in this absolutist category conflated the term “belief” with the terms “theory”, “inference”, or “hypothesis”. For example, students stated:

1. Science is based on beliefs in a hypothesis, but after an experiment you cannot make up the results, you take the results you got and that is not a belief. Science knowledge is based on some beliefs, but also based on facts.
2. I think it is sort of true because some science topics involve your beliefs, but most science uses facts. A fact would be that a mammal is a vertebrate and a belief is that a type of dinosaur is green.
3. I think that most of science is based on facts, but some of it is based on beliefs. A example of facts is that the existence of dinosaurs was proven, using bones. An example of beliefs is the Big Bang Theory.

Each student indicated that most science is based on “facts,” yet also “belief”. Looking to contextual clues, “belief” was likely used in the same sense as hypothesis, theory, and inference—indicating the presence of student alternative conceptions—such as a hypothesis is an educated guess (McComas, 1998) and theories are not grounded in evidence (Alters & Nelson, 2002). For example, in student statement number three: “Whereas the “existence of dinosaurs was proven, using bones”, the Big Bang Theory was not couched in any proof or evidence. A reiteration of the NOS learning experiences might include explicit student learning of what constitutes a theory, hypothesis, and inference, and how these terms are related to each

other and to other scientific constructs such as observation. I agree with Smith and Siegel (2004) that a distinction must be made between “belief” and what constitutes scientific knowledge in order to promote normative views of the nature of science. However, I am also mindful of Cobern (1994, 2004) who recommended that teachers avoid distinctions as doing so may promote science as an epistemic authority and discount student belief (religious). Cobern also recognized the confusing nature of the term belief, as people use the term in colloquial language in multiple ways. Therefore, I think future curricular modifications should entail a comparison between the colloquial and scientific use of terminology (i.e., inference, theory, hypothesis), and discussion of whether the use of the term “belief” is best suited for a scientific context.

Science and the natural, *present* world.

Overall, I was pleased about the pre/post questionnaire comparison of item #3, “Science can answer all questions” (Tables 4.5 and 4.6). The pre-questionnaire data indicated that students held normative conceptions that science is limited in the questions it can ask and answer, and excludes religious and metaphysical questions. The post-questionnaire data indicated improvements through further clarification. No participants indicated that science answers questions about the natural world in the pre-questionnaire. This percentage increased to 41% post-questionnaire. However, student understandings of what constitutes the natural world were not evident, so future curricular improvements should consider activities that guide students in developing criteria for the “natural world” and distinguishing between science and non-science questions as suggested by Smith and Siegel (2004).

Three students brought up a salient points in questionnaire item #3 worth consideration. These students indicated that science was limited to questions of the present world. For instance, one student explained. “Science cannot answer...questions that happened when they were not

documented years ago”. Only three of the thirty-four participants responded in such fashion; however, more participants may harbor this same alternative conception, and this alternative conception may interfere with learning evolutionary theory. Therefore, I would modify a future iteration of this NOS curriculum to include discussion of indirect observation in answering questions about our past. This would also be a logical scaffolding technique to prepare students with the idea of indirect observation in reconstructing our hominin past.

Validation of the NOS Questionnaire

I used the extant skull focus group interview data to assess the validity of my NOS questionnaire. Because of time limitations, I was not able to have focus group participants expand on all five of their NOS questionnaire responses, because the purpose of the extant skull focus group interviews was also to have participants share their experiences with the extant skulls and share their prior knowledge of evolution. Therefore, I limited conversations during these focus groups to revisiting the statement, “Science is a system of beliefs”. I capitalized on the benefits set up by the focus group setting, and used follow-up questions so that students could expand on their views. These follow-up questions sometimes asked students to consider the before mentioned statement, but in context with the extant skull learning experiences.

- What is our understanding of these skulls based on?
- What was the main scientific skill that you used while looking at the extant skulls?
- How did you learn about your extant skull?
- Is what we know about these skulls based on beliefs?
- What is your understanding of observation and inference at this point?
- How would you define observation?
- Using your skull, share an observation and related inference.

I used data provided by five participants to help assess the validity of the NOS questionnaire. I compared student responses on the post NOS questionnaire with their responses during the extant skull focus group interviews. The extant skull focus group interviews transpired after the administration of the post NOS questionnaire. A comparison of this data suggested some validity of the NOS questionnaire.

Four students expressed absolutist views of science on both the post NOS questionnaire and the extant skull focus group interview, suggesting questionnaire validity. For instance, one student explained on the post NOS questionnaire, “I think it [science] is based more on observation because people with different religions and cultures will have different beliefs”. This same student provided a similar response in the context of the focus group interview. He explained,

I think that the statement ‘Science is based on beliefs’ is false. Because, if two scientists have two different religions they are going to have different beliefs on it. So it should be ‘Science is based on observations’, cause if they both observe, they’re going to get the same results.

The similarity of responses from questionnaire to focus group response may suggest that the NOS questionnaire had some validity.

However, one student’s views differed when comparing her post NOS questionnaire and the focus group interview data, suggesting a lack of questionnaire validity. This student expressed absolutist views on the questionnaire, saying, “Science is based on facts. A hypothesis may be based on a fact until proven with facts. So, science knowledge is based on proven facts”. This questionnaire statement was categorized as “absolutist”. This same student revealed less

absolutist thinking during the focus group interview when she said that “I think if the scientists get the same result then you can infer that it’s possibly correct”. “Possibly correct” insinuated tentativeness. Like Lederman (2007, 1990), this study revealed the limitations of a paper/pencil instrument in culling valid student views; on the surface, students may present absolutist views, but when queried further, reveal more normative thinking.

The responses of four out of five students was consistent when comparing their post NOS questionnaire with and focus group interview response. This may suggest that the questionnaire may provide some trustworthy indication of student views. However, the inconsistency with one student’s response suggests that claims should be carefully drawn from the NOS questionnaire and corroborated with other lines of evidence.

Overall Summary/Reflection of the NOS Learning Experiences

Three major points should be considered when summarizing the inductive analysis of my NOS unit. First, students may have developed more absolutist views of science because of the NOS curriculum intervention. Curricular changes may need to teach the NOS concept of science as empirical in tandem with science as subjective and tentative in order to promote normative views of NOS. I will have to consider how to teach science as subjective and tentative without relaying the idea that science is flimsy and shaky. Second, students appeared to demonstrate alternative conceptions of the scientific terms “inference, hypothesis, and theory” and even conflate these terms with “belief,” indicating that the scientific terms have no relationship to observation/evidence/data. Future curricular modifications may need to explicitly teach the colloquial versus scientific use of terminology. Third, an important alternative conception emerged from the questionnaires. Three students indicated that science cannot answer questions

about the past. I will consider how to integrate the concept of indirect observation and retrodictive inquiry into future NOS curricular interventions.

However, I would keep one component of the NOS unit, the Which Lens is Best learning experience. Data from the focus group interview data suggested that this learning experience may have helped students negotiate the perceived conflict between science and religion. I asked focus group participants, How do you deal with what you learn in science and what you learn in church?”. Two students referred back to this learning experience when answering this question, suggesting its potential to help students “find a place to stand” (Scharmann, 1990, p. 98)

I think how you taught us earlier about the different glasses and how you have to look at things when you have the science glasses, and most of the time most people will believe in it. Because they are in science and they know what they are observing and looking at. But then maybe later when they are not working on science they will believe that it's not true or may believe it both ways but like in different environments.

Four other students gave similar explanations—they compartmentalized science and religion which is not ideal, but may be a better alternative to shutting completely down during evolution instruction.

These findings provoked teacher reflection. I think in my anticipation of student resistance (regarding the teaching and learning of human evolution), I overemphasized science as empirical, based on observation, and dependent on honesty, clarity, and accuracy. Maybe I overemphasized these NOS concepts, so that students could not dismantle the theory of evolution, with notions of evolution as “just a theory”. Perhaps I need to review the purpose of instruction, to get students involved in a conversation of evolution, help them “find a place to stand” (Scharmann, 1990, p. 98), and help them to gain understanding, but relinquish any

expectations for the outcomes of belief or acceptance. In the NOS learning experiences, I also attempted to make a distinction between belief and observation. Yet the focus group interview data suggest that the use and understanding of the term “belief” is diverse, unlike the term “observation”. Student views of observation converged on synonymous terms such as fact and what could be gleaned by using the five senses. However, students used the term “belief” in various formats. Some referred to the term in the religious sense, or conflated the term with “inference”, “hypothesis”, and “theory”. Explicit instruction regarding the difference between these terms may help students apply these terms in more normative ways.

Skull Presentation Performance Tasks: Results of Inductive Analysis and Rubric Scoring

Inductive Analysis Results

Inductive analysis of the extant and extinct skull presentation performance tasks rendered five emergent categories for consideration. These categories included: a) using and applying the terms “observation” and “inference”, b) engaging in comparative anatomy, c) generating logical inferences based on observation, and d) applying osteological terminology to describe skull characters. I described these emergent categories below. The data behind these themes informed research questions three, six, and seven: What student abilities of inquiry are demonstrated as students apprentice as paleoanthropologists, How do my conceptions of teaching and learning of human evolution change during the study as I engage in teacher research, and How should the curriculum intervention be modified based on teacher and student data sources?

Uttering “observation” and “inference”.

Coding the skull presentation performance tasks revealed the language that 7th grade science students used to describe a skull. Their language ranged between representing normative

practice to representing alternative conceptions. For instance, when making an observation of a skull, some students stated “I observed”, “I saw that”, or “the foramen magnum was...”. Student’s introductions to their observations fell within normative terminology, with “I observed” being the optimal utterance. Students’ description of their inferences, however, revealed a broader range between normative and alternative conception. In line with normative verse, students often followed the description of an observation, with “I” or “we” “inferred that...”. In line with alternative conceptions, students followed a description of an observation with “I believe that..”, or simply stated an inference as a fact. For instance, one student said that “the foramen magnum was directly underneath the skull, so it walked on two legs”.

Engaging in comparative anatomy.

During both the extant and extinct skull presentations, students made comparisons between their skull and others in the class when making observations and inferences. For instance, one group of students reported that the brain case of the deer was larger than a cat’s, but smaller than a human’s, and therefore, the deer was likely more intelligent than a cat, but not as intelligent as a human. During the extinct skull presentations, one group of students observed that the brain case of *Homo neanderthalensis* was larger than *Homo sapiens*, and therefore, may have been more intelligent. Therefore, students used the library of skulls available as reference points to describe their own skull under study.

Making logical inferences based on observation.

Another emergent category from analyzing the transcripts of student presentations included making logical inferences based on observation. Students often and thoroughly made inferences about the life of their skull, linking these inferences back to observation. For instance, one group of students stated that the coyote’s eye position was at the front of the skull, and

therefore, the coyote most likely was a predator. Another group of students observed that *Australopithecus afarensis* had a slight, sagittal crest, and inferred that the bite must have been strong. All student presentations were infused with such examples of sharing inferences in tandem with the related observations.

Use of scientific terminology.

Also, prolific in the student presentations was the use of scientific terminology. The students fluently shared the scientific name of their skull, and proceeded to describe it using osteological terminology. This osteological terminology (i.e., dental formula, incisor, canine, premolar, molar, mandibular molar, sagittal crest, brow ridge, sexual dimorphism, foramen magnum, brain case, prognathism, etc.) was initially presented to students through the observation of the gorilla skull and reinforced through its presence on graphic organizers for observing the extant and extinct skulls. The students successfully transferred this prior experience with this scientific terminology to their presentations before a peer audience.

Summary of the Inductive Analysis of Student Presentation Tasks

The inductive analysis of the extant and extinct skull presentations rendered a set of categories describing what students were actively doing and achieving during their presentations. Students a) used and applied the terms “observation” and “inference”, b) engaged in comparative anatomy, c) generated logical inferences based on observation, and d) applied osteological terminology to describe skull characters. These categories were then used to create a grading rubric to be reapplied to the presentation data for more quantitative analysis. The results of applying this rubric are shared in the following section.

Last, these categories suggested that students were engaged in situated learning, learning couched in the discipline of paleoanthropology. Students were emulating the language and

practices of paleoanthropologists. Like paleoanthropologists, they were also collaborating together.

Student-Participant Presentation Task Rubric Results

Twelve groups of students were analyzed for the extant skulls presentations. There was one group of one, nine groups of two, and one group of three individuals who presented—totaling 23 participants in all. Thirteen groups of students were analyzed for the extinct skull presentations. There were five groups of one, four groups of two, three groups of three, and one group of four—totaling 23 participants in all. There were fewer participants represented in the skull presentations compared to the other data collection pieces such as the NOS pre/post questionnaire, which had 34 participants. There were less participants due to various competing factors: participants were absent because they were sick, making up CRCT testing, or on field trips with their exploratory classes like band and chorus. And due to classroom logistics and time, it was difficult to have students make up their presentations. On the other hand, making up a questionnaire could be done independently without whole class and teacher participation. Some of the presentations also only had one individual presenting, meaning that their partner was absent, since the learning experiences prior to the presentations had participants working collaboratively as in the discipline of paleoanthropology.

Table 4.11 presented all group scores for both the extant and extinct skull presentations. Table 4.11 also summarized the group scores statistically, reporting the range, mean, median, and mode. The results suggested an improvement from the extant skull presentations to the extinct skull presentations. A comparison of the range statistic suggested that the range of presentation scores decreased; there was less variation in scores for the extinct skull

presentations. Mean presentation scores improved from 60 to 72, median scores improved from 62 to 72.5, and mode scores improved from 64 to 72 and 77.

Table 4.11. <i>Summarizing Statistics of Extant and Extinct Skull Performance Tasks</i>					
	n=	Scores			
Extant Skull Presentations	12	40, 43, 49, 54, 60, 61, 63, 64, 64, 69, 76, 77			
Extinct Skull Presentations	13	55, 66, 67, 71, 72, 72, 72, 73, 77, 77, 77, 78, 82			
	n=	Range	Mean	Median	Mode
Extant Skull Presentations	12	40-77	60	62	64
Extinct Skull Presentations	13	55-82	72	72.5	72, 77

Figure 4.1 showed improvements between the extant and extinct skull presentations in all domains measured. Collectively, presentation groups uttered the terms “observation” and/or “inference” 4.6 times during the extinct skull presentations compared to 3.4 times during the extant skull presentations. References to comparative anatomy were made three compared to 1.6 times on average, and logical inferences were made 8.2 compared to 6.8 times. There was a slight improvement (a 0.2 increase) from the extant to the extinct skull presentations in reference to the frequency of osteological terminology applied. And, in regards to presentation skills, ten presentation groups achieved the level of “consistent command” during the extinct skull presentations, compared to only three during the extant skull presentations.

Teachable Moments During the Student Presentation Tasks

Teachable moments occurred during both the extant and extinct skull presentation performance tasks. These teachable moments transpired between skull presentations as presenters transitioned to their seats, and as the next presentation group prepared.

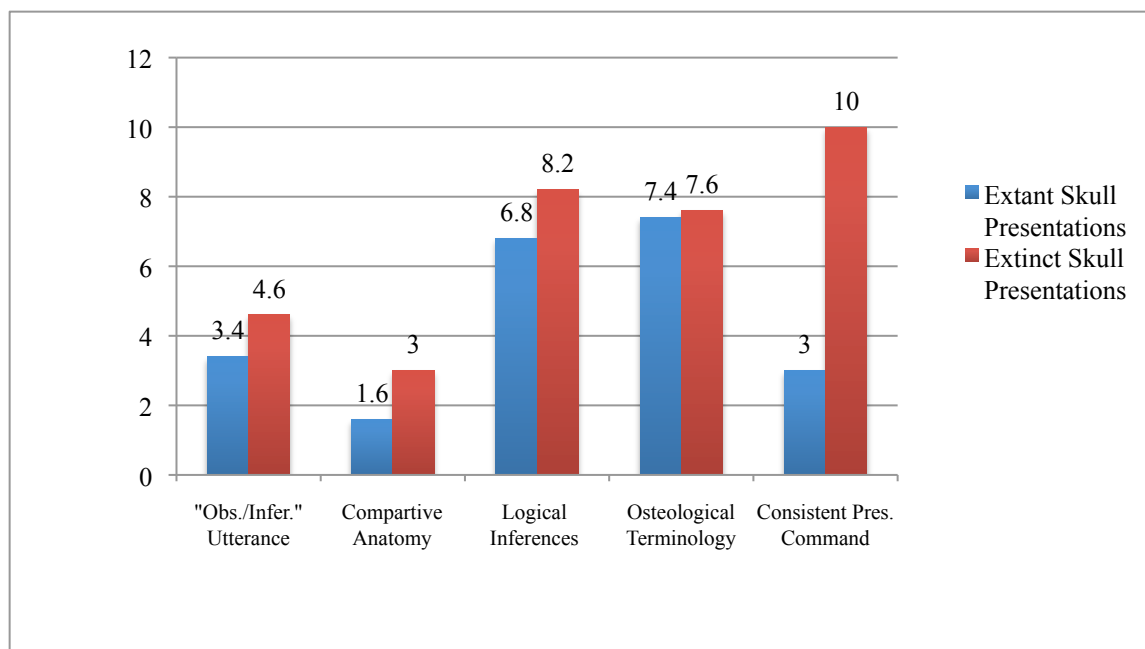


Figure 4.1: Graph Comparing the Extant and Extinct Skull Performance Tasks. The numbers on the graph represent average rubric domain scores.

Teachable moments transpired as a blend of lecture, whole group discussion, Socratic questioning, and table talk (student-participants discussing topics with their neighbor) in order to help student-participants think about big ideas of evolutionary theory and the NOS. I used teachable moments to link learning back to earlier learning experiences, or introduce new ideas as well. The skull presentations and embedded teachable moments were video recorded, so I was able to specifically document them below.

Teachable moments during the extant skull presentations.

During the extant skull presentations, teachable moments linked learning to NOS concepts explored through the NOS pre/post questionnaire (i.e., science as empirically based and science as dependent on honesty, clarity, and accuracy). However, I also used teachable moments to introduce other concepts, such as science as tentative, the distinct relationship between observation and inference, basing claims on evidence, and the evolution of dentition. The following teachable moments occurred during the extant skull learning experiences:

- The evolution of teeth-After the presentation of skulls representing herbivores, carnivores, and omnivores, I challenged learners to think about the evolution of the different types of teeth. I led learners to first think about the most ancient vertebrate in our skull collection and according to the fossil record. Students decided upon our reptilian outlier, the alligator. We discussed its dentition of 80 canines, leading to the realization that incisors and molars arose later in vertebrate evolution. Students were asked “Why?” and they fielded possible explanations. They were also asked how we could have the selection for different types of teeth, and at the same time have organisms like the alligator that have maintained a more ancient dentition.
- Modeling scientific language: I was careful in all of my communication with students to model scientific language. I consistently used terms such as observation, inference, evidence, claims, etc.
- Relationship between observation and inference: I spoke to students about the relationship between observation and inference. And, if we are going to be honest and accurate as scientists, we need to be clear in our speech when we are referring to observation versus an inference. I told students there was a big difference between observation and inference, with observation being a fact and established through consensus, with an inference being based on observation and subject to change.
- Science as tentative: I used several skull examples to demonstrate how science could change. These examples challenged students to think about how science would change if we could also observe the living animal in addition to just the skull. For instance, I talked about how observations of just a gorilla skull, might render inferences that the gorilla bite was strong, and that the gorilla fought a lot. However, this inference might

change into fact, if we observed gorillas over decades (like Dian Fossey) and directly observed this gorilla behavior.

- Basing claims on evidence: Between presentations, I reminded students that if they made a claim (an inference) they had to back it up in science. The accurate and honest codes of science would have us to do so.
- Correcting student language: Between presentations and sometimes during presentations, I would correct student language. For instance, one student participant would share an observation and then proceed to say that he “believed” rather than “inferred” a certain characteristic or behavior based on his observation. I reminded this student that the term “believe” means different things to different people, and that the more appropriate term in science would be “infer”.

The extant skull presentations and the teachable moments embedded within, established added context for future discussion regarding the NOS and evolution. Below, I share the teachable moments that occurred during the extinct skull presentations.

Teachable moments during the hominin skull learning experiences.

The extinct skull presentations also created ripe opportunities for teachable moments. Teachable moments occurred more frequently compared to those during the extant skull learning experiences. Teachable moments reinforced concepts previously considered or introduced new ones. To scaffold teachable moments, I created a PowerPoint presentation to show relevant slides after each hominin skull presented. I also used magazine images, such as imagery from the National Geographic article, “The origin of childhood” (Sloan, 2006). The PowerPoint and magazine images showed skull comparisons of hominids, scientific renderings of what hominins might have actually looked like, fossil dig sites, and paleoanthropologists at work in the field. I

summarize these teachable moments below, and organize them under teachable moments in a) paleoanthropology, b) the NOS, and c) evolutionary theory.

First, teachable moments addressed specific issues related to the discipline of paleoanthropology. I challenged students to reconsider the statement, “Humans evolved from monkeys”, identify criteria for designating a hominin as human, recognize the data behind dating fossils, and visualize the working environments of paleoanthropologists:

- Reconsidering “Humans evolved from monkeys”. I proposed this question between skull presentations for students to consider. Students were encouraged to turn to their neighbor and discuss this statement. By the end of the presentations, I had students share their responses to this statement.
- Considering what it means to be human: I periodically challenged students to think about what it means to be human, and what criteria scientists might use to distinguish the hominins as either human or not human.
- Dating fossils: The concept of dating fossils arose during the extinct skull presentations. I briefly addressed this concept, given the prior knowledge dealing with chemistry needed for more detailed discussion. I shared the idea that scientists can look at carbon and argon atoms in the sediments in which fossils were found, do a chemical analysis on this sediment, and determine and estimate the age of the fossil.
- Representing paleoanthropology: I used magazine articles and projected PowerPoint images to show renderings of what hominins might have actually looked like, actual fossil

dig sites, and the conditions that paleoanthropologists work under (e.g, dig site in the Afar region of Africa). I emphasized the collaborative nature of paleoanthropology and the contribution of local tribesmen in such collaborations.

Teachable moments regarding the NOS also transpired. NOS concepts that were revisited but applied in the new context of extinct hominins included:

- Basing claims on evidence: Prior to posing questions to students (e.g., Which hominin skulls are more human-like versus ape-like), I reminded them that “if you have an idea, you need to back it up by reasoning” or “if you make a claim, back it up with evidence”.
- “Evolution is just a ‘theory’”: Between one or more hominin skull presentations, I asked students to think about the statement “Evolution is just a ‘theory’”. I asked students to talk about their ideas with their neighbor, and then share ideas to the whole class during group discussion. I tried to lead students to see that what we know about evolution is based on observation and evidence. During this teachable moment, I also reminded students that the term “theory” is used differently in science than in everyday language.
- Modeling scientific language: I took care during these teachable moments to use specific, scientific language (e.g., observation, inference, claim, evidence, data).
- Differentiating between observation and inference in a new way: After each extinct hominin presentation, I used PowerPoint or magazines to show scientific renderings of how hominin species might have actually looked. We discussed how this imagery was an inference, based on observations of skull characters.
- Science as tentative: I used the *Sahelanthropus tchadensis* as an example of how science can change. The skulls of *tchadensis* is warped due to the fossilization process,

and making the position of the foramen magnum uncertain. Students suggested that new fossil finds of this species might change what we know, and provide evidence regarding whether *tchadensis* walked on two legs or four.

The consideration of new NOS concepts arose during these teachable moments as well:

- **Unanswered questions:** Student often asked questions after each presentation. For instance, students asked, “What happened to those scientists who contrived Pilt Down man?”, and “How did Lucy’s kind go extinct”, or “Could this hominin not have evolved into another hominin? I used these opportunities to turn the question back on the students, and suggest that they might explore this question further in the independent research they were conducting at home as a part of the extinct skull learning experience: Independent Research. And or, I might have explained that scientists are currently asking that same question, such as which hominins are in the *Homo sapiens* line, and which are evolutionary dead ends.
- **Science done poorly:** The student presentation of Piltdown Man introduced a new NOS concept: Science can be done poorly. I told students that Piltdown Man was a paleoanthropological fraud, contrived from a human skull and orangutan jaw, and presented as the missing link between chimpanzees and *Homo sapiens*. I explained to students that some scientists do bad science, probably for reasons of fame and finance. However, I reminded them that Piltdown Man was eventually revealed as a hoax, because of the skeptical and fact-checking nature of science.
- **Truth claims:** Whenever a student used the word “true” or truth”, I reminded them that this term was not the best term to use in science, because it insinuates complete

understanding and closes opportunities for more learning. I informed them that it was better to say that “The evidence supports the claim that...”. One teachable moment that came up in the context.

Teachable moments regarding evolutionary theory also occurred, naturally arising in context or in response to student-participant inquiry:

- Identifying evolutionary trends: I periodically challenged students to identify evolutionary trends. I tried to lead students to see characteristics shared by all hominins (such as bipedalism) as well as trends regarding evolutionary change (e.g, selection for larger brain case).
- Evolution as bushy rather than tree-like: I challenged students to consider the relationships among hominins (as a preamble to constructing the Hominid Hallway phylogeny). For instance, I asked them if the hominins evolved one into the other in a step-wise, ladder-like fashion, or if there was evolutionary branching. The idea of extinction and evolutionary dead ends was revealed. Students were challenged to visualize hominin relationships in terms of a bushy evolutionary tree rather than a ladder.
- Contemplating evolutionary time: I challenged student-participants to try to conceptualize evolutionary time, using Lucy dated to 3.2 million years ago. I asked student-participants to first think about the notion of one million, referring the wall of one million asterisks hanging out in the hall. I also challenged them to think about the number of generations that would have to pass, from Lucy’s species to the evolution of *Homo sapiens*.

- Inferring age, cause of death, disease states, and behavior: The observation of some hominin skulls rendered unique stories for discussion. For instance, our *Homo neanderthalensis* skull displayed, a) pin holes in the skull indicative of iron deficiency, b) two large impressions in the skull suggestive of the a bite inflicted by predator, c) no teeth indicative of old age and the possibility that fellow kind were providing care.
- Discussing contemporary species: At certain points I had student-participants point out other hominin species that may have lived at the same time as the specimen they presented. We pretended what it might have been like if two different species came face to face.

I think teachable moments enhanced learning experiences, even though they were more teacher-centered. I think they may have been effective because they were embedded within the rich context of students presenting the hominin skulls to each other, and directly and explicitly linked to this experience. The teachable moments allowed me as the teacher to help students continue conversational trends regarding big ideas, as well as introduce new concepts to be further considered in subsequent, more student-centered learning experiences.

Summary of Data from the Student-Participant Presentation Tasks

In sum, the data rendered from the analysis of video of the extant and extinct skull student-participant presentations supports several claims. First, this data supports the notion that student-participants engaged in the essential features of inquiry (NRC, 2000, p. 29) because they:

- a) Engaged in scientifically oriented questions,
- b) Gave priority to evidence when making claims (i.e., linking inference to observation),
- and
- c) Communicated explanations to their peers.

Second, students explicitly considered one of the most important NOS concepts (Lederman, 2007) because they

- a) Differentiated between observation and inference.

Third, students engaged in situated learning (Lave & Wenger, 1991) because they

- a) Emulated the work of mammologists and paleoanthropologists, and
- b) Used and applied scientific terminology in context.

Fourth, student-participants improved based on the comparison the extant and extinct skull presentation data, suggesting effective scaffolding and alignment of the two performance tasks. Last, NOS conversation initiated by the NOS pre/post questionnaire (i.e., science as empirically based) were continued as documented by teachable moments, but nuances to this NOS concept were introduced, such as NOS as tentative.

The student-participant presentations of the extant and extinct skulls provided some of the most rewarding moments for myself as the teacher. I enjoyed being the guide on the side, allowing my students to take center-stage to demonstrate what they knew and were able to do. These skull presentations also provided pivotal teachable moments for making connections with more abstract evolutionary and NOS concepts. Although not measured, I think learning may have been optimized by the synergistic combination of a) student-participants engaging in authentic experience, and b) teachable moments encouraging additional sense-making. I attribute the curriculum design principle of backwards design (Wiggins & McTighe, 1998) in helping me conceptualize student performance tasks, and then work backwards in developing sequential learning experiences to help students prepare for these capstone events of learning.

Curriculum improvements might have had student groups present two skulls at once (e.g., a carnivore versus a herbivore during the extant skull presentations, and an extinct hominin

versus an extant ape during the hominin skull learning experiences). I think this additional curricular piece would have encouraged more comparative anatomy and would allow students to work more closely with a variety of specimens. One student-participant offered another suggestion: provide additional extinct skulls, but extinct skulls representing ancestors of non-human mammals. Also, the teachable moments that arose organically and sometimes spontaneously provided ideas for curricular expansion in the area of explicit NOS instruction. One idea might have students complete a summarizing activity post presentations listing examples of how science/paleoanthropology is tentative.

Pre Focus Group Interview Findings: Extant Skull Learning Experiences

Twenty-four student participants comprised six focus groups. One group of six, two groups of five, one group of four, and two groups of two participants contributed insights regarding the use of 3-D extant skull replicas in teaching and learning. The inductive analysis of student views generated three themes for discussion: a) affective outcomes, b) cognitive outcomes, and c) prior knowledge of evolutionary concepts. I refer to these findings as pre focus group data.

Introduction: Affective and Cognitive Outcomes

The data reported in this section suggested that these learning experiences tapped into the affective domain (Posner & Strike, 1992; Dole & Sinatra, 1998) of learning because they:

- Created a contextualized learning environment,
- Enhanced perceptions of learning, and
- Incited motivation to learn.

The interpretation of data also suggested that these learning experiences tapped into the cognitive domain of learning because they:

- Engaged students in inquiry (NRC, 1996; NRC, 2000),
- Developed understanding (Smith & Siegel, 2004), and
- Encouraged conversation regarding the nature of scientific observation and inference (Lederman, 2007).

Last, data generated established a basis of prior knowledge, which served as a reference for comparison with the extinct skull focus group data. Students shared their general knowledge of how evolution happens, the evidence supporting evolution, and evolutionary time. Students also commented on two alternative conceptions (i.e., Humans evolved from monkeys, and evolution is *just* a theory) and shared how they negotiated the perceived tensions between evolution and creationism.

Human Skull Learning Experience

Affective outcomes: Human skull learning experience.

The interview prompt, “Anything surprised you about your skull that you didn’t know about but learned about?,” was used to unpack student views about the Human Skull learning experience. Student responses to this question suggested that this learning experience engendered motivation; students expressed wonder regarding their own skull. One student explained that teeth were “cool” in reference to eating a cracker and thinking about teeth functions. Three others were “surprised” to learn the different functions of teeth, “that some were used for cutting, some were used for chewing, and like they can’t all do everything”. Two student participants used “weird” as a response to learning about how “the plates of the head grow together”. The use

of language such as “cool”, “weird”, and “I was just surprised,” suggested the human skull learning experience engendered interest/motivation to learn.

Cognitive outcomes: Human skull learning experience.

Focus group data also suggested that the Human Skull learning experience helped students gain knowledge, defined by Bloom, Engelhart, Furst, Hill and Krathwohl (1956) as recalling facts, terms, basic concepts and answers. Nine focus group participants identified the four different types of teeth and their functions, three students made comparisons between their own skull and the gorilla skull, one student shared his dental formula, one student recognized the stories that can be reconstructed from a skull, and five others noted the variation in teeth numbers when comparing data from classmates (the range in numbers of teeth in my classes was between 18 and 32). In addition to knowledge, students may have also gained some understanding (Smith & Siegel, 2004). Students began to transcend basic recall. They began making sense of the connections between their teeth (“I had only 27 teeth because I was missing one.”), teeth functions (“different teeth for different jobs”), and diet (“like how much it [teeth] can tell you about the animal. Like if it’s an omnivore and what it eats and all of that”).

Extant Mammalian Skull Learning Experiences

The inductive analysis of the focus group data regarding the additional extant skull learning experiences (i.e., Gorilla Skull Exploration, Extant Skull Drawing, and Extant Skull Presentations) suggested positive cognitive and affective outcomes. This section discussed the affective and then cognitive outcomes of students learning with 3-D extant skull replicas. Findings informed all seven of my research questions.

Affective outcomes: Extant mammalian skull learning experiences.

The interview prompts: a) What has surprised you about learning about these extant skulls, and/or b) What can you learn by just observing a skull?, initially unpacked student views. This data suggested that the 3-D extant skull replicas were a classroom hit; they enhanced the affective domain, inciting situational interest or extrinsic motivation (Table 4.12). Focus group participants frequently (19 times) used terms such as “neat”, “fun”, “cool”, “creepy”, and “favorite” to describe their experiences. Such positive feedback may be attributed to the tactile, 3-D, authentic, and/or novel nature of the skulls.

One of the more appealing qualities of having the 3-D skulls may have related to touch and feeling. One student explained that it was “kind of hard not to touch them when you’re not supposed to, like in homeroom”. Twelve total focus group participants brought up the tactile nature of having the skulls, often comparing their experiences against 2-D visual formats (I liked it a lot because like I said, when you are given a sheet of paper that has a skull on it you can’t really feel it, like feel the texture. And, you can’t really see it and observe it, and open its jaw). The 3-D skulls may have enhanced learning giving the tactile benefits. Other researchers like Jones et al. (2006) have also found that “touch matters” and can enhance learning of complex concepts (p. 111).

Some participants (n=4) referred to the authenticity of the skulls (“I was kind of surprised as they were the actual replicas of a real skull”, “you can handle them and that makes it twice as real”, and “it was more fun...cause we actually [got] to do it ourselves). References to an authentic learning environment may suggest that the 3-D extant skulls helped to create a contextualized environment for learning, simulating real-world phenomena. Other participants referred to the novelty of their experience, saying, “you’re not going to get another chance to

actually see all these skulls and observe them. Cause this is the only time we are allowed to do it”.

Sixteen focus group participants *perceived* that the 3-D extant skulls enhanced and/or facilitated learning—an indication that the skulls may have helped to create the optimal balance between challenging students, while also promoting student self-efficacy. One focus group participant explained, “I think it’s better than just seeing them on the screen because you can touch them and you can really see them 3-D. It’s a lot easier to think about it”. Finally, and maybe most importantly, focus group participants wanted to know more; they wanted to engage in more scientifically oriented questions (an essential feature of inquiry) (NRC, 2000). For example, one student mentioned, “I’d really like to see ancestors of these extant skulls, so we can see the difference of how they’ve evolved through years”. John Dewey (1938) concurred that the most valuable learning experiences fueled the desire for more learning experiences--encouraged the habits of mind of a life-long learner, or in the case of science, a life-long inquirer.

Table 4.12
Extant Skull Focus Group Data: Affective Outcomes

Focused code	Initial code	#	Marker
Creating a contextualized learning environment	Recognizing authenticity	4	• I was kind of surprised as they were the actual replicas of a real skull. • You can handle them and that makes it twice as real. • I think its thumbs up too. Cause you're not going to get another change to actually see all these skulls and observe them. Cause this is the only time we are allowed to do it. And it's a great way to learn about these different animals and it's just better than looking at a picture. Then also you can see how big it is in real life.
	Doing science	2	• ... it was more fun I guess [than] just sitting here and someone talking and telling us about them. Cause we actually get to do it ourselves.
Enhancing perceptions of learning	Making learning easier (3-D)	16	• It made studying them easier because you can look at it from all angles instead of just a picture and stuff. • I think it's better than just seeing them on the screen because you can touch them and you can really see them 3-D. It's a lot easier to think about it.
	Touching and feeling	12	• I liked it a lot because like I said when I was presenting, when you are given a sheet of paper that has a skull on it you can't really feel it, like feel the texture. And, you can't really see it and observe it. And open its jaw. • Kind of hard not to touch them when you're not supposed to. Like when I'm in homeroom.
Inciting interest/motivation	Wanting to learn more	11	• I'd really like to see ancestors of these extant skulls, so we can see the difference of how they've evolved through years. • Since the alligator's sagittal crest is not on the top [of the skull], I would like to know where are the muscles attached. • How [is] the orangutan related to the gorilla because like their bone structures are similar and they both have a sagittal crest. • I would like to know how you could tell what sex it is from just the skull. Like the gorilla you can tell what sex it is but the mountain lion it's the same skull for both the male and the female. • Well, I can see on the top of the jaw that there's hole and I was wondering what those were.
	Thinking skulls are "neat", "fun", "cool", "creepy", "interesting", "favorite"	19	It was really neat to look inside of [the animal]. It was interesting because it's not like all the time you get to see a real skull. It's cool because its life size and hands on. It's just fun to play around with.

Cognitive outcomes: Extant mammalian skull learning experiences.

Focus group data also suggested that the 3-D extant skulls enhanced cognition. Student-generated data suggested that they developed:

- Abilities and understandings of inquiry (NRC, 1996; 2000),
- Understandings as defined by Smith & Siegel (2004) (i.e., connectedness, sense-making, application, and justification), and
- NOS understandings in regards to the nature of scientific observation and inference.

The following discusses these three cognitive outcomes and provides student-generated evidence as supports for any claims made.

Inquiry as a cognitive outcome.

The inductive analysis of the pre focus group interview data (post extant skull learning experiences) suggested that student-participants demonstrated abilities and understandings of inquiry (NRC, 1996; 2000) (Table, 4.13). First, student-participants shared their ability to make scientific observations (n=15). For instance, one participant observed, “how the male and female [gorilla] look so different because of the brow ridge and sagittal crest”, while another student observed that the lower jaw on the deer had incisors but the top did not. Six participants recognized differences in how the skulls looked in comparison to the living animal.

Table 4.13

Extant Skull Learning Experience: Inquiry Outcomes

Engaging in inquiry	Making observations		14	• I didn't know they [Great Dane] had a sagittal crest. Like I knew they had a little bump in the back, but I didn't know it was a sagittal crest. • [I] thought how the bottom half of the jaw [deer jaw] has incisors, but the top doesn't. I thought that was weird.
		Comparative anatomy	6	• And the sexual dimorphism, how the male and female look so different because of the brow ridge and sagittal crest. • How the extinct skulls are different from the ones that are living now. And how they changed over time. But how they are similar at the same time. • A lot of them are similar. The chimpanzee and the gorilla are similar in their structure. And the deer and the cow look similar in the way, just like the shape of their skull. Our skull was kind of unique because we're kind of the most evolved with our communication skills and our intelligence. • I was surprised by how much the skulls are the same because they have the same parts and everything. They might look a little different like you know the mouth like on the horse is really long. It has two sections of teeth, but they all have the same parts like the sagittal crest and the brow ridge. They all have the same teeth. They are just like shaped differently to help them live.
	Posing scientific questions		15	• How the extinct skulls are different from the ones that are living now. And how they changed over time. But how they are similar at the same time. • Well maybe like what they ate and what their habitat was like when back before they became extinct. • How do they get the DNA out of a dried fossil? And how can they figure out who's who? • I want to see how the one animal skull thing evolves to the next one and see if you see a lot of comparisons I guess. • I hope to...figure out why they went extinct based on their skull, like if they weren't smart enough or they didn't have enough protection of themselves. And that's what I would like to see. • I think it would be cool cause these are extinct and these are like the only remains that we have of them. They are the only thing we can observe. We can't observe them for real. So you could like observe it and make inferences about how they lived, what they ate. It would just be really cool. • I would like to learn how big their teeth are compared to the modern day extant skulls are. • How they compare and how they contrast basically. But just how different they are or why they got extinct or just some qualities about them that kind of made them different. • Most of those like Neanderthals and the other names I can't pronounce. Did they turn into the gorillas cause the gorillas are like with us. How can we evolve from apes pretty much from the human like skull.
	Formulating explanations from evidence		2	The observation was taking the two centimeter tooth, and then saying that it ate grass [was the inference].

Second, fifteen (Table 4.13) student-participants generated scientifically oriented questions during the pre focus group interviews. All of these questions related to what students wanted to learn about extinct skulls the next week. However, many scientifically oriented questions were generated regarding the extant mammals, corroborated by a look at student work samples (i.e., students generated three questions after they completed their drawings and an observation/inference chart during the extant skull learning experience three (i.e. Extant Mammalian Skulls) (Figure 4.2).

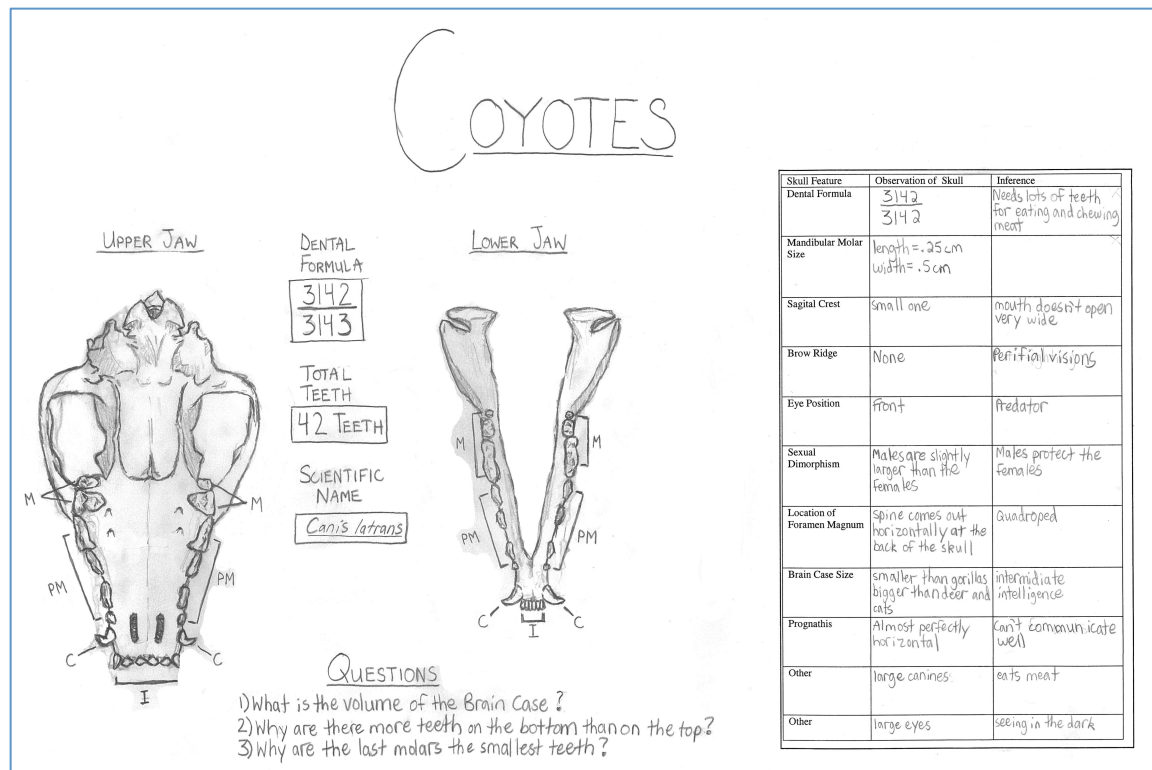


Figure 4.2. Extant Mammalian Skull Drawing and Obs/Inf. Chart. All student-participants (n=34) drew their extant mammalian skull, indicating the scientific name, labeling the teeth, indicating the dental formula, completing an observation/inference chart, and generating three scientifically oriented questions.

Table 4.14

Extant Mammalian Skulls and Scientifically Oriented Questions

Feeding role	Extant mammal	Student generated scientifically oriented question
Carnivores	Cat	• Why do cats have six incisors? • Why do cats have large eye sockets? • What is the volume of the skull case?
	Mountain Lion	• What is the sex of it [mountain lion]? • What are the purposes of the many holes in the brain case? • Why doesn't it [mountain lion] have more teeth?
	Great Dane	• What is the diet of the great dane? • How intelligent is the animal? • Why does the brow ridge fold over?
	Coyote	• How old was the coyote when it died? • How can you tell how old a species is by its teeth? • How big was the brain?
	Alligator (outlier)	• Why does the alligator have wrinkles on its skull? • Why does it have a small brain case for a large animal? • Why does it only have canine teeth?
Herbivores	Gorilla	• How big is the brain [of the gorilla]? • What do they [gorillas] spend their day doing?
	Horse	• How old is the skull? • Why is it's teeth so big? • How big is the brain case? • Why is the snout so long?
	Deer	• Why are the deer's molars so far away from the incisors? • Why do the teeth [molars] look like two, but are only one? • Why are there no canine teeth?
Omnivores	Human	• What percentage of the brain is used to house the skull • How strong is the human bit force? • How strong is the human sense of smell? • Why do humans have no sagittal crest?
	Chimpanzee	• Why are the canines so big [on the chimpanzee]? • What are the hoops on the side [of the chimpanzee]? • Why does the chimp male have a small brow ridge compared to the male gorilla?
	Orangutan	• Why are the eye sockets so large [on the orangutan]? • Is this a male or female orangutan? • Why does the sagittal crest [on the orangutan] go to the eyes? • Is there a reason for the under bite?
	Black bear	• How big is the brain? • How would the eyes attach to the socket [of the grizzly bear]? • Can you tell the exact type of food the animal eats from the skull? • Can you determine the size of the animal's body by observing the skull?

In addition to making observations and generating scientifically oriented questions, student participants demonstrated that they could “think critically and logically to make the relationships between evidence and explanation”—or in our case the analogous relationship between observation and inference. During the pre focus group interview, Students were able to give examples (n=2) of an observation of an extant skull, and the related inference. For example, one student-participant explained, “The observation was taking the two centimeter tooth, and

then saying that it ate grass [was the inference]. The number of students (n=2) who shared an observation and inference was low, because I did not want to spend a lot of interview time on this topic. Instead, I had students complete a reflection exercise after the learning experience three of the extant skull unit. I asked them to 1) define observation and inference, and give an example of an observation and inference using an extant mammalian example (Table 4.15). This data suggests that students were understanding the “critical distinction between observation and inference” that is an essential feature of inquiry (NRC, 1996; 2000) and the NOS (Lederman, 2007, p. 834). And, making the distinction between observation and inference may be one of the most foundational skills/understandings that 7th grade students should be developing.

Table 4.15

Extant Mammalian Skulls: Relating Evidence to Explanation

Feeding role	Extant mammal	Student generated scientifically oriented question
Carnivores	Cat	An observation is observing, or viewing, some using your five senses. For example, on the cat, you can observe their foramen magnum is vertical, so you can infer it walked on four legs.
	Mountain Lion	An observation is collecting information with your five senses. At inference is why you think you saw the observation. A mountain lion has sharp teeth. You infer it has sharp teeth for cutting meat.
	Great Dane	An observation is a fact that you can see, but an inference is an opinion or hypothesis based on an observation. This can be true for the observations of the extant skulls. For example, the foramen magnum on a great dane is horizontal, so you can infer that it is a quadruped. Also, it had very sharp canines, and very but, sharp molars, so you can infer that it is a carnivore.
	Coyote	[An] observation is something you see, hear, taste, touch, or smell. An observation from my extant skull is that its eyes face forward. An inference is a belief based on the facts from the observation. An inference from my extant skull [coyote] is that it is a hunter, because it's eyes face forward. Therefore, my belief is based on facts so it is an inference...
	Alligator (outlier)	An observation is something that is sensed, and is there. For example, the alligator skull had only canines. An inference is a possible explanation to an observation. For example, we can infer why the crocodile only had canines may be because it's a carnivore.
Herbivores	Horse	We made observations and inferences on the extant skulls we studies. An observation is something you can use your sense to make up a fact about what you are studying. For example, the mandibular molar size on the horse was very large, length and width wise. An inference is your own reasonable idea of theory of an observation of why there is that quality. For example, you could infer that because the mandibular molar size is large on the horse, the horse could be a plant eater...
	Deer	An observation is making a fact with your senses. For example, on the deer skull the molars were flat, but rigged. An inference is making an education guess. For example, I inferred that the deer is an herbivore because of its flat, rigged molars.
Omnivores	Human	There is a big difference between observation and inference. An observation is using senses to get data. An observation of a human skull would be that the eyes are in the front. An inference is a guess made from the observation. The inference could be, since the human eyes are in front, it is a predator with good depth perception.
	Chimpanzee	An observation is looking at something and an inference is what your conclusion could be looking at a subject. An example could be that because a chimp's foreman magnum is in the middle of the skull, it can be bipedal or quadrupedal.
	Gorilla	The difference between an observation and an inference, is that an observation is something you just look at and see. For example, in the sagittal crest in the gorilla, you can observe that males have one and females do not as much. When you infer, though, you are just guessing at why something is the way it is. So, you can infer that males are the protectors of the group, because they have the sagittal crest with more muscles.
	Black bear	There is a distinct difference between an observation and an inference. An observation is something observed with your own two eyes and is a fact. For instance, if I looked at a grizzly bear skull and observed it had two canines, that would be a fact. An inference is something that can be assumed from the observation. For instance, because the grizzly bear has two canines, I can infer it's not an herbivore. An inference is not a fact.

Understanding as a cognitive outcome.

Focus group data also suggested that students were developing knowledge and understanding. I defined knowledge as the recall of specifics and facts (Bloom, Engelhart, Furst, Hill, Krathwohl, 1956). I used Smith and Siegel's (2004) "four (admittedly overlapping) criteria for understanding: connectedness, sense-making, application, and justification" (p. 563).

Students demonstrated knowledge through the extant skull interviews. The evidence of student knowledge is fused into student conversations related to inquiry (Table 4.13) and observation and inference (Table 4.15). Student knowledge is also evident in their extant skull drawings (Figure 4.2). Students demonstrated knowledge of common and scientific names of extant mammals, the types of teeth, dental formula, skull characters, and the definitions of observation and inference. This knowledge served as a foundation for higher order demonstrations of inquiry skills and understanding (Bloom).

The extant skull interview data suggested that students engaged primarily in connectedness and sense-making processes of understanding. First, I considered how student-participants demonstrated understanding by making connections (Table 4.16). Gauld (2001) explained that “[u]nderstanding of some notion is made up of the ideas which are linked together and the connections which define the relationships between these ideas” (p. 5) (as cited in Smith & Siegel, 2004, p. 562). First, students-participants (n=20) connected the extant skull learning experiences with prior learning experiences with body systems (i.e., skeletal and muscular) and the Mountain Gorilla learned earlier in the year. They also made connections with prior knowledge (one student made connections between the external appearance of a Great Dane and its skull characters), and connections with how one observes a skull to reconstruct its life history.

Moreover, five students engaged in comparative anatomy (Table. 4.16), which I find similar to making connections. One participant shared that

“it’s really different when you have the skulls side by side and you get to point out what’s alike and what’s different. And say, oh well, this one has canines but this one has canines too. But wow, look at the difference in their molars. And point out differences like that. It’s nicer to have them side-by-side and actually look at them and touch them.

Several students showed surprise at how similar mammalian skulls are, given the differences of outward appearance. I think that curricular modifications might build on the power of comparative anatomy as evidence for common decent. However, I was pleased to see that students were engaging in comparative anatomy during the extant skull learning experiences, to build this skill as it is an essential skill in paleoanthropology (R. Bobe, personal communication, August 12, 2012).

Sense-making (n=7) activities also transpired (Table 4.16). Gauld (2001) defined sense-making as “making sense of something or attributing meaning to it” (in Smith & Siegal, 2004, p. 562). Initial codes of reconsidering prior knowledge and contemplating anomalies were subsumed under sense-making. For instance, four students grappled with the anomalous canines of the horse and gorilla, noting that these animals used their canines for fighting rather than feeding. Two student-participants reconsider their prior knowledge. For instance, one student-participant explained that she “didn’t know they [Great Dane] had a sagittal crest. Like I knew they had a little bump in the back, but I didn’t know it was a sagittal crest.

Table 4.16 <i>Extant Skull Focus Group Data: Enhancing Cognition</i>				
Focused code	Initial code		#	Marker
Making references to understanding	Making connections		20	- I had the gorilla and I thought it was really cool since we were observing and talking about gorillas so much. - I was surprised at how many things the skulls can show you. Like what you eat, if you are a predator of prey because of your eyes, how you communicate because of this thing, the prognathism. It was just real surprising what you could find out just by looking at skulls.
		Comparative anatomy	5	- A lot of them are similar. The chimpanzee and the gorilla are similar in their structure. And the deer and the cow look similar in the way, just like the shape of their skull. Our skull was kind of unique because we're kind of the most evolved with our communication skills and our intelligence. - I was surprised by how much the skulls are the same because they have the same parts and everything. They might look a little different like you know the mouth like on the horse is really long. It has two sections of teeth, but they all have the same parts like the sagittal crest and the brow ridge. They all have the same teeth. They are just like shaped differently to help them live.
	Sense-making	Grappling with the canine	4	- And, you can kind of tell that it's a gorilla from the skull. But, like when you see the teeth and things, it makes you think that it is not a gorilla. But you find out that the canines aren't really used for eating meat and stuff; they are used for breaking the bamboo. And so even though they may look like big and could hurt you and stuff, they normally just use it for fighting other gorillas. Not like hurting people and stuff. ...it [horse] has big canines for an herbivore...like since it has all the different kinds of teeth you would think it is an omnivore. But it only eats like grass and plants and stuff. And it uses its canines for fighting.
		Reconsidering prior knowledge	2	I didn't know they [Great Dane] had a sagittal crest. Like I knew they had a little bump in the back, but I didn't know it was a sagittal crest.

The data in Table 4.16 encourages me to think more about understanding in terms of the main goal of evolution education as defined by the science education community (Cobern, 1994; Smith & Siegel, 2004). The science education community agrees that students should come to understand why scientists think the way they do regarding evolution. However, the definition of understanding provided by Smith & Siegel (2004) appears to focus on students engaging in thinking processes of scientists, rather than on expressing the right answers in line with these experts. During the pre focus group interviews, student-participants demonstrated understanding through their thinking processes (Table 4.16) rather than on the minutia of scientific knowledge. I am pleased that my students were engaged in this higher level thinking (Bloom's revised

taxonomy), but wonder how this might be assessed and recognized in light of standardized testing which predominately tests for knowledge only.

NOS understandings as a cognitive outcome.

During the extant skull focus group interviews, we revisited our conversations regarding the NOS. The purpose was to: a) reflect on the validity of the NOS questionnaire (Figure 3.1), b) establish NOS understandings encouraged by the extant skull learning experiences, and c) establish a reference point for comparison during the post focus group interviews. I eventually wanted to see if student views of the NOS (e.g., observation) changed under the topic of human evolution.

We focused mainly on the NOS concepts of observation and inference during the extant skull focus group interviews, using the following interview prompts: What was the main scientific skill that you used while looking at the skulls? Is your understanding of the skulls based on beliefs? What is your understanding of these skulls based on? How would you define observation? What is the difference between observation and inference? The basic findings of this interview portion suggested that a) the NOS questionnaire was limited in unpacking student views b) students continued to hold absolutist views of science and conflate the term belief with scientific terms such as inference, and c) students showed cognitive growth in regards to defining observation and inference, and discerning the relationship of observation and inference in the context of the extant skulls.

First, the pre focus group interview data provided data to help assess the validity of the NOS questionnaire (Figure 3.1). I assessed the validity of the NOS questionnaire by comparing students' questionnaire responses to their interview responses. First, the focus group interviews revealed that students who expressed absolutist views on the NOS questionnaire may actually

hold more normative views of science once queried further. Three students expressed absolutist views of science during the pre focus group interview, and consistent with their responses on the NOS post-questionnaire. This data supported questionnaire validity. However, one student's response did not align when comparing her interview versus questionnaire response. On the NOS post-questionnaire this student-participant wrote, "Science is based on facts. A hypothesis may be based on a fact until proven with facts. So, science knowledge is based on proven facts". This questionnaire statement was categorized as "absolutist". However, this same student revealed less absolutist thinking during the focus group interview when she said, "I think if the scientists get the same result then you can infer that it's possibly correct". "Possibly correct" insinuated tentativeness. This discussion revealed that the simple categorization of student views of NOS as either "absolutist" or "normative" might be over-simplistic; students may hold a combination of absolutist and normative views when they are further queried during the interview process. Lederman (1990) made a similar discovery when assessing the validity of his NOS questionnaire.

Second, students used the term "belief" inconsistently, as the NOS questionnaire indicated. Some participants conflated belief, with either opinion, religion, or inference (n=3). This brings up the question of whether to have 7th grade students contemplate the place of belief in science. I have concurred with both Cobern (1994) and Smith and Siegel (2004). I have concurred with Cobern (1994), because I have recognized through this study that students bring various notions of belief to the learning situation; the single term begets different emotions and thinking from learner to learner which makes the collective discussion of the term difficult. However, I have also agreed with Smith and Siegel (2004), that an honest consideration of the NOS, include the consideration of belief. The challenge becomes defining belief in contrast to

the epistemology of science, without minimizing belief, and threatening some students' worldviews and motivation to learn. Based on this study, I have concluded that belief be considered less directly and less explicitly; in other words, avoid explicitly comparing belief to the NOS science. However, the focus should remain on defining scientific observation, inference, hypothesis, and theory and the relationships with one another. And, when the term belief arises, suggest more appropriate language in the context of science--explaining that the term belief means different things to different people, and may not be the best term to use for this reason. In spite of explicit instruction, however, learners may still conflate the terms, vary in their explanations of them, (as do the practitioners in science and science education). Perhaps the importance piece is that learners are engaged in the conversation.

Third, students showed cognitive growth in regards to their understanding of observation, and the relationship to observation and inference. Undetected by the NOS questionnaire, students conveyed pluralistic notions of observation (i.e., observation as “looking”, “using the five senses”, retrodictive, factual, dependent on consensus, and inherent to the development of scientific theory (Table 4.17). I was pleased by this finding. Seventh grade students are capable of considering the NOS concept of observation in a multifaceted way. Students also discussed the concept of observation in context with 3-D extant skulls. Four students confided that what they knew about the skulls was based on observation and inference. One participant, explained, “I agree with Natasha, because pretty much the only ways to determine what they do [extant mammals] and what they look like is observations. And then when you get the observations you can make inferences to tell or guess more about them”. My students were possibly learning that observation and inference were essential to understandings skulls. Would they also see

observation as essential in understanding human evolution? The post focus group interview data might reveal such insights.

One point of success during the focus group interview emerged when one participant noted the tentative nature of science, even when observing extant skulls—the known world. She explained, “it’s [understanding of skulls] mainly based on observation because we can sit here and look at them and understand. But then it’s sort of based on beliefs and inferences because we can sort of assume things by our observations but we’re not positive.” I was pleased that this student was using careful language, “not positive”—and indication that she was adopting the habits of mind of a scientist who maintains healthy skepticism. However, she also conflated the terms belief and inference suggesting room for improvement. It would be interesting to see if students would enhance notions of science as tentative after the hominin skull learning experiences.

Also an indicator of success, students may have clarified the relationships between observation and inference. One participant explained, “I just learned more that inferences come from observations. And that you can’t infer anything. You’ve got to infer something that relates to the observations”. I was pleased to see that this student was engaging in NOS conversation—conceptualizing the relationship between observation and inference. This comment suggested that we might have made explicit inroads to recognizing the concrete relationship between observation and inference. The previous data presented in Table 4.15 (reporting data from student reflections) corroborates this data culled from pre focus group interview. Students grappling with the relationship between observation and inference was important, because this relationship is also analogous to the relationship between evidence and explanation—an essential feature of inquiry (NRC, 1996; 2000) and the NOS (Lederman, 2007).

Table 4.17

Extant Skull Focus Group Data: Science, Belief, and Observation

Focused code	Initial code	n=	Marker
Absolutists views of science	Basing science on facts or observation	4	• ...everybody might have their own opinions, but science is just the one thing that's not based on anything except for facts. • I think the statement that science is based on beliefs is false. Because if two scientists have two different religions, they are going to have two different beliefs on it. So, it should be that science is based on observations, cause if they both observe, they're going to get the same results.
Conflating belief with	religion	2	I think the statement that science is based on beliefs is false. Because if two scientists have two different religions they are going to have two different beliefs on it. So it should be science is based on observations cause if they both observe they're going to get the same results.
	inference	1	It's [understanding of skulls] mainly based on observation because we can sit here and look at them and understand. But then it's sort of based on beliefs and inferences because we can sort of assume things by our observations but we're not positive.
Observing is multifaceted. Observing is	looking	1	When you look at something and you write down where it is and stuff I guess.
	using the five senses	1	An observation is like something you can sense with your five senses. So, it has like a small brain case. But then an inference would be that it has a small brain because a big brain couldn't fit in a small brain case.
	retrodictive	1	Kind of like CSI. You have the skulls and then based on the skull you can kind of work backwards.
	factual	1	It's like a fact and you could agree like the Great Dane has sharp canines. It's not like we believe. It's actually a fact.
	depends on consensus	2	It's like a fact and you could agree like the Great Dane has sharp canines. It's not like we believe. It's actually a fact.
	renders scientific theory	1	They [scientists] made more and more observations to support their inferences and become a very known and accepted theory [evolution].
Discussing observation in context with extant skulls	Understanding is tentative	1	It's [understanding of skulls] mainly based on observation because we can sit here and look at them and understand. But then it's sort of based on beliefs and inferences because we can sort of assume things by our observations but we're not positive.
	Understandings is based on observation and inference	4	I agree with Natasha, because pretty much the only ways to determine what they do and what they look like is observations. And then when you get the observations you can make inferences to tell or guess more about them.
Relating evidence and explanation using extant skulls	Linking observation to inference	2	I just learned more that inferences come from observations. And that you can't infer anything. You've got to infer something that relates to the observations.
	Giving an example of observation and inference	2	The observation was taking the two-centimeter tooth, and then saying that it ate grass [was the inference].

Last, students may have been developing understandings of observation through “intentional conceptual change” (Southerland & Nadelson, 2012, p. 365), an approach to teaching and learning evolution that requires learners to consistently reflect on learning frameworks and pre/post exams to examine their own personal knowledge and beliefs. Southerland and Nadelson (2012), for instance, encouraged their learners to examine Dole & Sinatra’s CRK model and other knowledge/understanding/acceptance pre/post measures throughout the learning process. Likewise, my students were encouraged to consistently think

about the role of observation, inference, and belief in science, beginning with NOS questionnaire, and continued through studying, drawing and presenting extant skulls, teachable moments, reflection pieces, etc.

Prior knowledge of evolutionary theory.

Another purpose of the extant skull focus group interviews was to establish students' prior knowledge of evolution, before entering into our inquiries into extinct skulls and human evolution. I wanted to gain a more in-depth baseline of their understanding of evolutionary concepts, in order to later see the affect of the hominin skull learning experiences on these conceptions. Several months prior to this research study, my students and I taught and learned requisite concepts as defined by state standards –namely exploring natural selection and components inherent to this theory (e.g., variation, mutation, competition, environmental change, survival of the fittest, producing more young than will survive, etc.). The evolution of the peppered moth, giraffe, and Komodo dragon were used as examples to demonstrate natural selection in my classes. So, I knew students would be bringing relevant knowledge to hominin skull learning experiences, and that knowledge needed to be established for the purposes of both teaching and research.

I began this portion of the focus group interview by asking participants: “Has anything surprised you about what you’ve learned about evolution this year so far?”, and/or, “What stood out about our evolution unit in January”? Subsequent conversation led to follow-up questions such as: How would you define evolution?, Can you give me an example of natural selection that we learned about that helps you understand it?, How long does evolution take?, What misconceptions about evolution do people have? Should evolution be in the science book?,

Should evolution be taught?, How do you deal with what you learn in church and what you learn in science?, and What would you like to learn about extinct skulls during the next week?

Prior knowledge of evolution.

Table 4.18 organizes the first portion of our conversations regarding evolution and includes what surprised them about earlier evolution learning experiences, their explanations of evolution, and the evidence they provided during these explanations. Four students were surprised about macro-evolutionary concepts. We previously explored an image in our textbooks of the fossil record of vertebrates, and how the fossil record suggested the historical age of fish, amphibians, reptiles, birds, and mammals; with fish arising on the planet first, followed by the other vertebrates. One student demonstrated surprise of this notion saying, “I didn’t even know amphibians evolved from fish, and then I didn’t know that they evolved into reptiles”. Statements such as this may demonstrate that learners brought general notions of macroevolution to learning experiences, and that they may have had an interest in learning more about macroevolution.

All participants queried were able to explain evolution, yet these explanations ranged between demonstrating normative to teleological thinking, while one participant demonstrated a blend between the two (Table 4.17). Eleven students demonstrated teleological thinking; species changed because they needed to, and they actively chose to change based on this need. This conception remained in spite of my own instructional attempts to explicitly combat its prevalence. One student explained that the giraffes “needed to be long-necked to get the tree leaves and eat”. These results are consistent with the literature; students often maintain alternative conceptions even after instructional interventions of natural selection, perhaps pointing to the difficulty of the topic and the strength of prior conception (Kelemen, 2012).

Table 4.18

Extant Skull Focus Group Data: Exploring Students Prior Knowledge of Evolution

Focused code	Initial code	#	Marker
Showing surprise about	macroevolution	4	- I was surprised because I thought it was weird how an animal could go from walking...a quadruped. And then two thousand years later the descendant could be a biped. How that would work. I thought that was cool. - I didn't even know amphibians evolved from fish, and then I didn't know that they evolved into reptiles.
Explaining evolution	Demonstrating teleological thinking	11	The giraffe lesson really helped me understand what evolution was. Because it showed that how the giraffes were so short necked [and] how they needed to be long-necked to get the tree leaves and eat. So that really helped me understand it [evolution].
	Demonstrating normative thinking	16	- I was going to say natural selection, and the zebras that are most successful in the habitat will survive. And the ones that are not will die. But the ones that do survive will pass on the genes and more zebras like that one will be born. - Birds that had the beaks suitable for the environment--like they would get a food source so they would be able to reproduce and the birds with non-suitable beaks would die. And so eventually they'd pass their traits down. - Okay, it's not really their choice whether it [evolution] happens or not. Like they just keep going and then along the line one of them has a genetic mutation. It turns out to be better. Then they start living longer and the other ones start dying off. And then the ones that lived, they keep reproducing and keep living.
	Demonstrating teleological and normative thinking	1	I think of evolution as a series of events that changes in an animal so it can adapt or the whole species so they can adapt to the change in times. Like the ice age they had to adapt and get fur because if they didn't have fur they would have frozen. And then when the ice age went away they couldn't have fur or not a lot of fur cause they would get hot. This change would occur through natural selection. An animal would be picked by nature (well not actually picked) but it would be better suited than the rest and that one would keep breeding and eventually it would become better suited for nature.
	Conceptualizing human evolution	3	- I think about other animals like the horse. I do think it [the horse] evolved from other animals. But just the human thing. I don't think it [humans] did [evolved]. - If there was a bird that killed people with blue eyes but the people with the blue eyes wouldn't survive to pass on their genes. The people with the brown and green eyes would. And so it's kind of like a game of chance where the environment lets certain things with natural selection pass on their genes and that gives the surviving population more of a chance to have that. And then a better of chance till let's say a thousand years the only humans left were the brown and green eyed humans. It's a weird example... - I believe misunderstandings about evolution is that we came from a single cell organism. We started out and we evolved into humans from one single cell organism. I believe that's one of the biggest misunderstandings. Is the single cell came into a two cell which it just passed on its genes and it grew larger then it spread out and it became several different species which became more species afterwards. And that mutations just changed the species a little. So that it would be a different thing.
Providing evidence for evolution	Referring to homologous structures	2	Like they have whales, and then evolution can't just be a theory. There can be a lot of facts behind it. You can take a whale and then take its fin and see how the bones in the fin, and then like further back a few million years ago, they found another animal that had similar bones in its fin. And so they can infer that they evolved from that.
	Making inferences about ancestry from fossils	2	Fossils [are evidence for evolution]. You can see that they're similar cause the more fossils you find if you see similarities you could automatically make an inference that they were probably similar in ancestors. And that could evolve to thinking about natural selection and maybe how that species became extinct and why and how the ones that were naturally selected for what adaptations they had to make them survive.

More students than not, however, (n=16) demonstrated rays of normative thinking, indicative that 7th graders can grapple with a complex topic such as natural selection, and that previous instruction facilitated this concept. One participant said,

Okay, it's not really their choice whether it [evolution] happens or not. Like they just keep going and then along the line one of them has a genetic mutation. It turns out to be better. Then they start living longer and the other ones start dying off. And then the ones that lived, they keep reproducing and keep living.

One student also used natural selection to explain how evolution occurs, but merged teleological and normative verse when explaining the ice age and animals with lots of fur. This student used normative language such as “adapt” and “better suited”, but simultaneously insinuated that species changed in response to cold environmental conditions. Establishing student prior knowledge on the topic of evolution was revealing and important. This base-line of data would become important when making comparisons to focus group data captured after our hominin skull learning experiences. How would students explain evolution, but in the context of human evolution? Would they be able to apply notions of natural selection to humans?

Interestingly, students brought up (unsolicited) the topic of human evolution when discussing their notions of evolution. One student demonstrated acceptance of horse evolution, but not human evolution. Another student used human eye color as an example of natural selection (a true demonstration of understanding as this student applied natural selection knowledge to a novel example), while another student explained that the public has a misunderstanding of human evolution (i.e., the public perceives human evolution as humans spontaneously arising from single celled organism). I found participant references to human

evolution as interesting, as I did not prompt this conversational direction. Perhaps they anticipated that we were going to broach this topic, or that prior discussion of human evolution engendered cognitive dissonance, or perhaps they had interest in learning more about human evolution. I considered these references to human evolution as indicators of motivation, a positive prerequisite for future learning.

Prior knowledge of evolutionary time.

Table 4.19 cataloged our focus group conversations regarding evolutionary time. I broached this topic with my students during the focus group interviews, asking, “How long does evolution take?” and in most instances how long they thought evolution took place in the examples they were already explicating (e.g., giraffe, peppered moth, wholly mammoth, zebra). The extinct skulls learning experiences would explicitly address concepts of deep time through the example of human evolution; sound pedagogy would have students grapple with deep time because the literature has suggested that students harbor alternative conceptions regarding this topic (Tamir & Zohar, 1991; Newport, 2004); the literature has also suggested the use of deep time frameworks (macroevolution) in order to pedagogically approach the teaching and learning of evolution in a more holistic manner (Catley, 2006). Future learning experiences would attend to deep time concepts (e.g., constructing human phylogenies), so I also wanted to establish baseline student views of evolutionary time to see if the hominin skull learning experiences influenced their thinking of evolutionary time.

Table 4.19

Extant Skull Focus Group Data: Exploring Students Prior Knowledge of Evolutionary Time
(n=21)

Focused code	Initial code	n=	
Contemplating evolutionary time	Less than thousands of years	6	Like with the peppered moth, it [evolution] didn't take thousands of years. Like it happened really quickly. So, it [evolution] doesn't always take a long time.
	Thousands of years	5	I'd say evolution takes many thousands of years. It just doesn't happen just over night because it just takes time to change.
	Millions of years	3	Evolution takes millions of years to occur.
	Dependent on reproductive cycle	4	It depends on the organism because more insects and stuff will most likely evolve faster than others because of how they are made and their life span and stuff. And then more advanced animals like mammals would take longer because they have long lifetimes. Then, it takes longer for them to grow and pass their genes down. So it would take longer than other animals because how they are made.
	A long time	3	[The evolution of the wholly mammoth takes] lots of lifetimes cause you have the one organism that won't survive so you have to wait till he dies and then the ones that will survive they still have to pass on the genes themselves to be more genetic mutations, so they'll all the way get up to they have a lot of fur and stuff. So it will take a long time.

Participants expressed views regarding evolutionary time. Most students expressed that evolution takes “a long time”. Seven students explained what they meant by a “long time” using natural selection and reproductive cycles. They explained that changes would take time to accumulate in a population based on the life span of the species. For example, one participant explained that the evolution of the woolly mammoth took

lots of lifetimes cause you have the one organism that won't survive so you have to wait till he dies, and then the ones that will survive they still have to pass on the genes themselves to be more genetic mutations. So they'll all the way get up to they have a lot of fur and stuff. So it will take a long time.

Four of these seven students recognized that evolution could occur over relatively short amounts of time in addition to long time spans. They referred to the evolution of the peppered moth; a punctuated environmental shift combined with the short life span of the peppered moth revealed visible change within a species during a human lifetime. Five students said that evolution takes “thousands” of years, while three students said that evolution takes “millions” of years. Six

students thought evolution took less than thousands of years. I was pleased that students were thinking about evolutionary time, and also foresaw potential for future inquiries to engender more developed understandings of this topic, particularly macroevolution or speciation.

Prior knowledge of common misconceptions.

I had participants respond to two commonly stated phrases in our culture (also alternative conceptions). I asked students what they thought about the statement, “Humans evolved from monkeys”, and “Evolution is just a ‘theory’”. The Hominin skull learning experiences would explicitly address the problematic nature of these statements, and learning theory would support this pedagogical approach as alternative conceptions often create cognitive and affective boundaries for the accommodation of normative views. And, the “monkey” and “theory” statements are often used to dismantle evolutionary theory (Daugher & Boujaoude, 1997, 2005; Nehm & Schonfeld, 2007 Sinatra, et al., 2003 Woods & Scharmann, 2001). Students were exposed to these two statements previously during our evolution unit earlier in the school year. So, there was a reference point for our consideration of these statements during the pre focus group conversations.

Prior to this research study, I proposed the idea that humans shared a common ancestry with monkeys. I recalled drawing a crude phylogeny on the board relating contemporary humans, apes, and monkeys to common ancestral origins. During this piece of the pre focus group interviews, I expected that students would still express alternative conceptions given the lack of intensive consideration of the topic. Table 4.17 summarized student responses to “Humans evolved from monkeys”. A total of thirteen students shared their responses to this statement.

Most students (8 out of 13 or 62 %) agreed with the statement “Humans evolved from monkeys”. Two of these eight students demonstrated alternative conception (e.g., “... there’s a lot of evidence to support that we did evolve from them [monkeys]”). However, six of these eight students demonstrated a blend of alternative and normative conception (e.g., “We did evolve from apes. Maybe apes evolved from monkeys, but I think on some level, we may have [evolved from monkeys].” As a teacher, I was pleased that students were thinking in terms of humans having primate ancestry. However, as a researcher, I was not able to discern if these students visualized these ancestors in the like image of contemporary species or in resemblance to contemporary species (ancestral species that were ape- or monkey-like).

The remainder of participants (five out of 13 or 38%) disagreed with the statement “Humans evolved from monkeys”, suggesting normative conception, at least on the surface. A subset of these five individuals (n=2), expressed normative thinking:

I don’t think they [humans] directly evolved from monkeys, but maybe we shared a common ancestor and the common ancestor branched into primates and *Homo sapiens*.

But, I don’t think we directly evolved from them [monkeys].

However, three of these five students expressed a blend of normative and alternative conception. One student stated, “I think we probably evolved from apes and not monkeys, because they [apes] are more similar to us, like chimpanzees and stuff”. I interpreted that this student thought that humans evolved from apes (meaning larger brained primates without tails), which is more normative thinking. However, this student also suggested that human ancestors may have been “like chimpanzees”, which may have suggested that this student thought that humans evolved from contemporary chimps, an alternative conception. As a researcher, I should have probed this student further. My shortcomings as a researcher became evident here.

The findings in the last two paragraphs suggested room for cognitive improvement. These findings may have also supported more recent conceptual change theory (Dole & Sinatra, 1998 & 2008; Strike & Posner, 1992) that establishing a learner's prior knowledge is messy—not a simple codification into alternative and normative conception. Students may hold a blend of alternative and normative conception.

Table 4.20 <i>Extant Skull Focus Group Data: Responding to “Humans Evolved from Monkeys”</i> (n=13)					
Focused code	Initial code		N=	%	Marker
Responding to “Humans evolved from monkeys”	Showing agreement	Alt. concep.	2	15	...there's a lot of evidence to support that we did evolve from them [monkeys].
		Blend	6	46	I think we did evolve from apes. Maybe apes evolved and not monkeys, because they are more similar to us, like chimpanzees and stuff.
	Showing disagreement	Blend	3	23	I think we probably evolved from apes and not monkeys, because they are more similar to us, like chimpanzees and stuff.
		Norm. concep.	2	15	I don't think they [humans] directly evolved from monkeys, but maybe we shared a common ancestor and the common ancestor branched into primates and <i>Homo sapiens</i> . But, I don't think we directly evolved from them [monkeys].

Table 4.21 <i>Extant Skull Focus Group Data: Responding to “Evolution is just a theory”</i> (n=15)				
Focused code	Initial Code		Pre	Marker
Responding to “evolution is ‘just’ a theory” Evolution is...	not empirically based	Not based on facts	4	Scientists can't really prove that evolution was happening so they don't have a lot of facts to support it.
		Tentative	2	Well science it's not all 100% accurate, so all things that scientists have observed and made inferences about are just theories. Because they don't know 100% that that can be true because it's possible that we aren't seeing everything and it just might not be true.
	empirically based	Fact/proof/observation	3	Well maybe it's not “‘just’ a theory” because of looking at all the skulls of the similar ancestors and the fossils of some more ancestors you could see that they've evolved and so to say the same they've evolved in evolution because you have proof that they've changed.
		And “theory” (idea, inference)	4	That part of it is true because it [evolution] is an idea, but they have found a lot of facts on that idea. And using radioactive dating and then finding fossils they could support [it]. They really heavily support that [evolution].
		but religious influence	2	I think it [evolution] is sort of the truth, but we can tell from our evidence that they're related. But because of the controversy over religion and how God put the animals on Earth people don't want to accept that. But at the same time, we have facts, and then you have religion, and they are supposed to be separated because [you can] confuse them.

Student responses to the statement “Evolution is just a theory” (Table 4.21) showed:

- A total of eight focused codes—two subsumed under the focused code, “not empirically based”, and six of subsumed under the focused code, “empirically based”.
- An array of student prior knowledge, consistent with current conceptual change theory which claims that students’ prior knowledge on a particular topic is diverse and can not be codified as either alternative and normative (Dole & Sinatra, 1998, 2008; Strike & Posner, 1992).
- Where student responses landed in terms of conceptual movement toward more normative thinking.

Before explaining how I coded student data, I need to explain “how I knew what I knew” so to speak, concerning students’ expression of the term “just” and “theory”. During our evolution unit several months earlier, my students and I considered evolution as “just a theory”. When I proposed this statement to students, I emphasized “just” and “theory”, using inflexion to ascribe weakness/shakiness to the term evolution. I explicitly tried to rephrase the statement, as well, to clear up what I meant. I followed with questions, “Is evolution just a guess?”, “just a whimsical idea?” So, I used “Evolution is just a theory” as it is used in colloquial terms to provoke some initial theoretical conversations regarding the concept of scientific theory.

At this time, I used the cell theory as an example of how scientists use the term theory in a different way than we use theory in common conversation; I told students that scientific theory is not a simple guess but is an explanation based on decades, even centuries of observation and exploration. I talked about cell theory (students had a framework of understanding because of our cell unit in the fall) to bring home this point; our understanding of cells is based on decades of observation and study. I followed this line of logic with the scientific notion that evolution is

not “just a theory” as we understand theory in colloquial terms. Evolution is also based on decades of study. So, students had briefly considered the statement, “Evolution is just a theory” previously, yet through a simple lecture format with minimal discussion. I approached the first focus group experience with the idea that students still held alternative conceptions regarding the nature of a scientific theory. Students had not had explicit and reflexive opportunities to grapple with this concept, yet the extinct skulls learning experiences might offer fertile ground for more in-depth consideration. Baseline data for the construction of notions of scientific theory are considered in the following paragraphs.

When transcribing and presenting data, I indicated the scientific use of the term theory, without quotations. If I interpreted that a student was using the term theory in lay terms, I put the work in quotations. The focused code “not empirically based” included six student responses. Four of these students agreed that evolution is just a “theory”, meaning evolution is just an idea, with “not a lot of facts to support it”. Two of these students conflated observation and inference with the colloquial use of the term “theory”, however their conceptual views were coded as more developed because they expressed the “tentative” nature of science. One of these students explained,

Well science it's not all 100% accurate, so all things that scientists have observed and made inferences about are just theories. Because they don't know 100% that that can be true because it's possible that we aren't seeing everything and it just might not be true.

It was commendable that this student recognized the limitations of science and the limitations of our human ability to perceive.

Nine students were codified in the focused code “empirically based” because they asserted that evolution was based on either observation, fact, or proof. Three of these nine

students who argued that evolution was based on either proof, fact, or observation only—represented of absolutist thinking. Four of the nine students explained that evolution was “fact” and “theory”—“theory” used synonymously with idea or inference:

That part of it is true because it [evolution] is an idea, but they have found a lot of facts on that idea. And using radioactive dating and then finding fossils they could support [it]. They really heavily support that [evolution].

I was pleased that these students recognized the empirical basis of evolution, but there was room for conceptual improvement regarding understandings of scientific theory.

Two students-participants expressed that evolution was “empirically based with religious influence”. These students recognized the discrepancy between science which teaches that “we evolved from the apes” and religion that teaches that “we were made by God”. I did not press these students to develop their responses. I was reluctant to do so, as I wanted any conversation about religion to emerge freely from students. However, I think conceptual views could improve to demonstrate more understanding of the boundaries of science to address the nature world only.

No students expressed that evolution was empirically based yet tentative, and an explanation, and corroborated with multiple line of evidence as in any scientific theory. Room for conceptual improvement existed.

Prior knowledge of religion and science.

This focus group interview data also revealed insights regarding how students negotiate what they learn in science and what they learn at home or in church. Student input ranged from hard-lined positions, to those of compromise or compartmentalization. One hard-lined response included the perception that science and religion are at two, competing, dichotomous ends (“like enemies”). Another more hard-lined student view advocated science as a “non-biased” discipline

based on “observations and inferences” and others who perceive evolution as going against their religion or faith “jump to conclusions” and “just need to have a science class again”. Other students were more gentle in their deliveries. One student explained that her mom thought evolution was “hog-wash”, but she (the student) took an alternative stance--blending science and religion, suggesting that God could have created the world and its living things in the beginning; evolution then took over to create changes over time. I coded six student responses as compartmentalizing, a technique to facilitate “culturally border crossing” (p. 271) back and forth between one’s own culture and the culture of science (Aikenhead & Jegede, 1999). One of these students explained,

I think how you taught us earlier about the different glasses and how you have to look at things when you have the science glasses, and most of the time most people will believe in it. Because they are in science and they know what they are observing and looking at. But then maybe later when they are not working on science they will believe that it’s not true or may believe it both ways but like in different environments.

I interpreted this student excerpt as suggesting that one can embrace the culture of science when in science class, but then also embrace an alternative culture when not in science class—one can “culturally border-cross” with relative ease by drawing on compartmentalized views relevant to a particular environment. Several students of like input referenced the NOS lesson in utilizing different glasses to represent different epistemologies. This focus group data may suggest that the NOS glasses lesson was useful in giving students a “place to stand” other than at a polarizing extreme. I followed discussions dealing with science and religion, with another prompt, “Should evolution be taught?”. All five students who responded to this prompt agreed that evolution should be taught for reasons such as, “evolution is such a great possibility that without evolution

we may not be here today. So we need to learn about how we got here, and how we are, and what we are". I think this statement attested to the positive attitude most students brought to learning more about evolution, and even human evolution.

Table 4.22

Extant Skull Focus Group Data: Prior Conceptions of Science and Religion

Negotiating science and religion	Polarizing science and religion	1	I think like science and religion are like opposites like enemies. Because they try to solve the same things but they do it in different ways. Like religion it's like God created everything and the science the big bang theory how the molecules just blew up.
	Advocating science	1	They jump to conclusions. A lot of it is beliefs but science doesn't take science shouldn't have beliefs in it. They base their information on observations and then inferences. And so scientists kind of its not a biased party so if you just kind of look at the facts and say well ok there are similarities between the two skulls like between the chimpanzee and the human. They are similar brain case size like you could say that. And then and that's more of a trait of evolution it's not like and a lot of people are like they are saying we came from different animals. That we evolved from them millions of years goes against my religion or it goes against my faith and that's what people think it isn't they're not. They just need to have a science class again.
	Blending science and religion	1	I just think that most people they take evolution as a bad theory because of everything. But I'll mention evolution to my Mom and she'll be like oh that's a bunch of hogwash. But I think that people think just because God put things on the earth doesn't mean that there could be evolution like say God created humans and fish and bears or something that could still evolve to other things. And we could get more creatures so that means evolution could still happen but not necessarily change everyone's beliefs.
	Compartmentalizing	6	- I think how you taught us earlier about the different glasses and how you have to look at things when you have the science glasses, and most of the time most people will believe in it. Because they are in science and they know what they are observing and looking at. But then maybe later when they are not working on science they will believe that it's not true or may believe it both ways but like in different environments. Like in science class you may, but at home you may not. It may be true, but you may like I don't know how to explain it. You may have doubts about it I guess. - Well I sort of take what we learn in science and then I learn it and then when I go to church I learn that too. But then I keep in mind that science is just a theory pretty much back to the last question. And even though that all these things can be proved so much they're not positive yet. And so one little thing can't change all your thoughts but you have to be able to go back and forth. - Just like [Sonya] said my friends said that half of science is wrong. And he's saying that he's not really thinking or he's using his religious glasses or you know so when he says half of science is wrong he's thinking of his religion not about science itself. If he was using like you know science isn't necessarily wrong it's just its own little thing. So like I wouldn't say it's wrong or its right. But it's just there and you know somebody else might have an opinion about its wrong. But you know it's not necessarily wrong. - You just when you're a scientist like [Lane] said the glasses thing. You have to be a nonbiased party. You can't think of your religion or your upbringing or anything like that. You just have to record your observation with honesty clarity and you know that kind of thing. You just you have to base science on something that's an observation that's proven. Or inferred by many to actually. You can't jump to conclusions. - And whatever you think about evolution you really have to look through like we did that activity with the glasses you have to look through the science view. And you can't look through like social studies or religion or something you have to really take what you know about science and think about it that way instead.
Teaching evolution	Promoting teaching evolution	5	I think it should be because evolution is such a great possibility that without evolution we may not be here today. So we need to learn about how we got here, and how we are, and what we are.

Another positive came from student responses to the prompt, “What would you like to know about the extinct skulls that we will be learning about next week?”. Students eagerly shared what they wanted to learn more about such as, “the year they went extinct, what they looked like, what they did”, “how they changed over time”, “why they went extinct”, and “how they compare and how they contrast”. This input suggested that students were motivated to learn about human evolution. Previous experiences with the extant skulls learning experiences may have prepped such positive attitudes.

Corroborating the Data

Comparing the student-generated data rendered from the 1) NOS post questionnaire, 2) the extant and extinct skull presentations, and 3) the pre focus group interviews, rendered trends for discussion and also suggested the corroboration of data in order to make stronger claims. The claims supported by corroborated data included students:

- Developing knowledge and understandings of science content (i.e., comparative anatomy of skulls) and the NOS (i.e., the distinction between observation and inference).
- Engaged in the essential features of inquiry (i.e., learners engaged in scientifically oriented questions, giving priority to evidence in responding to questions, and formulating explanations from evidence (NRC, 2000).
- Engaged in situated learning (i.e. students emulating the language and practices of paleoanthropologists), and
- Engaged in “intentional conceptual change” (Southerland and Nadelson, 2012, p. 365) through continuous reflection on beliefs.

First, students demonstrated that they were progressively building knowledge and understanding over the course of the extant skull learning experiences. Both data from the skull

presentations and pre focus group interviews showed that students were building knowledge of common and scientific names of extant mammals, skull characters, dental formula, and definitions of observation and inference. These same two data sources also provided corroborating evidence that students developed understanding as students a) engaged in comparative anatomy and b) made connections between observation and inference (yet in the context of mammalian anatomy). My data supporting claims of student understanding is important given the consistent goal of evolution education to promote student understanding (Smith, 2010a, 2010b; Smith & Siegel, 2004; Southerland & Nadelson, 2012).

Second, corroborating evidence suggested that students engaged in the essential features of inquiry (i.e., learners engaged in scientifically oriented questions, giving priority to evidence in responding to questions, and formulating explanations from evidence (NRC, 2000). Learners engaged in scientifically oriented questions, ranging in questions provided by myself as the teacher (Table 3.1) and answered through learning experiences (i.e., extant and extinct skull presentations) to those posed by students during the pre focus group interviews (Table 4.13 & 4.14). Students also gave priority to evidence and linked explanations to evidence when presenting their extant and extinct skulls (Figure 4.1), when creating their drawings of skulls (Figure 3.14), and when generating skull inferences during the pre focus group interview (Table 4.15). Beardsley, Bloom, & Wise, 2012 have recently stated that guided inquiry using “actual data” and challenging students to justify explanations of this data may be the most effective strategy for the teaching and learning of evolution at the middle school level (p. 307) .

Fourth, several data sources (NOS post questionnaire and pre interview data) corroborated the claim that students were engaging in “intentional conceptual change” (as cited in Southerland and Nadelson, 2012, p. 365) by explicitly reflecting on the relationships of

observation, inference and belief in science. This active reflection can be seen as positive even though students continued to a) conflate terms such as belief, theory, inference, and idea, and b) demonstrate absolutist views of science. These two outcomes were also corroborated, leaving room for conceptual improvement, and hopefully engendered by the hominin skull learning experiences.

Summary: Results of the Pre Focus Group Interview Data

Overall, the first focus group interview data rendered interesting, rich, and developed conversation. Students benefited from the extant skull learning experiences regarding both the affective and cognitive domains of learning. Corroborating this data with the data rendered in the NOS questionnaire and extant/extinct skull presentations, suggested that students were building their skills of inquiry and building their knowledge and understandings of both comparative anatomy and the critical NOS feature of discerning the relationship observation and inference.

Students also demonstrated that they also brought readied conceptual frameworks for the future learning with extinct skulls. In other words they demonstrated that they could engage in conversations regarding evolution, natural selection, nature of science, evolutionary time, common cultural misconceptions, and science and religion. They also demonstrated motivation to learn more about the extinct dominion. The data suggested that student views varied, however, (i.e., absolutists, normative, and alternative), leaving room for conceptual improvement to be achieved through the instructional intervention of the hominin skull learning experiences.

Post Focus Group Interview Findings: Hominin skull learning experiences

Twenty-five student-participants comprised seven post focus groups. Three groups of four, two groups of three, one group of six, and one group of one participant(s) contributed

insights regarding the use of 3-D extinct hominid skulls during learning experiences. The student-participant make up of pre to post focus groups was inconsistent given the difficulty of assembling students based on their individual schedules. For example, students A, B, and C assembled for a pre focus group, but only students A and B could assemble on the same day and time post intervention, as student C went on a band fieldtrip and had to merge with another focus group on another day. To deal with this challenge, I compared pre and post focus group data in a collective sense similar to summary statistics (i.e., In general, what are student views pre intervention compared to post intervention?). Also, I tracked the responses of individuals, to show changes occurring at the level of the individual. I used the same coding schemes developed during the description of the pre focus group interview data, to add clarity for making pre to post comparisons. However, new initial codes had to be created and added to the original coding framework.

I codified student-generated data into two main themes: a) affective outcomes and b) cognitive outcomes. The general separation of data into these two themes occurred based on the influence of Dole and Sinatra's (1998) CRK model of conceptual change on my thinking about teaching and learning. And the findings rendered from the post focus group interviews informed all seven of my research questions.

Affective Outcomes

Introduction.

Focus group interviews rendered data suggesting that the hominin skull learning experiences tapped into and enhanced the affective domain of learning (e.g, motivation, attitudes, self-efficacy, and emotions) (Dole & Sinatra, 1998; Posner & Strike, 1992; Sinatra, Brem & Evans, 2008). This finding was important given research that emotions and motivation may be

the single biggest predictor of conceptual change (Sinatra & Pintrich, 2003), and the biggest barrier to accommodating normative views of evolution (Smith, 2010b).

In this section, I present the five focused codes related to the affective domain that were created during the inductive analysis process: a) positive emotive language, b) situated learning, c) enhanced perceptions of learning, d) privileged access and e) novelty, shock, and disgust. I present the data behind these focused codes because the interview data alone created “a story in itself that hardly requires much extra descriptions and explanations” (Roulston, 2010, p. 202). After showing the data, however, I make connections between my focused codes and the literature discussing motivation in general (Hidi & Harackiewicz, 2000), and motivation applied to the teaching and learning of evolution (Dole, Brem, & Evans, 2008; Dole & Sinatra, 1998; Rosengren, Brem, Evans, & Sinatra, 2010; Smith, 2010b,b). Therefore, the framework of focused codes generated by student data blended with my own conceptual framework influenced by my own readings of the literature. I try to make explicit the distinction of student data versus my interpretation of this data.

Readings from the literature helped me make sense of student data regarding the affective domain of learning. I used the work Hidi and Harackiewicz (2000), Dole & Sinatra (1998), and Dole, Brem, & Evans (2008) to help make sense of the data subsumed under my overall theme of “affective domain”. Hidi and Harackiewicz (2000) defined situational interest and extrinsic motivation, and provided examples of each in educational contexts. They (Hidi and Harackiewicz’s, 2000) defined situational interest as motivation “generated by certain conditions and/or stimuli in the environment that focus attention, and it represents a more immediate affective reaction that may or may not last” (p. 152), and intrinsic motivation as motivation “to engage in activities for their own sake” (p. 157). Dole & Sinatra’s (1998) Cognitive

Reconstruction of Knowledge model applied to the teaching and learning of evolution (Dole, Brem, & Evans, 2008) also helped me make sense of my data. They discussed the important motivational constructs of dissatisfaction, personal relevance, social context, and need for cognition, which also helped me make sense of my findings.

I made the following claim based on student-generated data. The hominin skull learning experiences engendered both situational and intrinsic motivation, which may have increased student engagement during learning, thus increasing the potential for conceptual change (Dole & Sinatra, 1998).

Positive/emotive language.

Students used positive and emotive language when they described their experiences with the hominid skulls, which may have been an indication of both situational interest and intrinsic motivation. They used language as in the extant skull interviews (i.e., neat, fun, cool, creepy, interesting, and favorite), but added descriptive emphasis with language such as: “mysterious,” “surprising,” “incredible,” “amazing,” “fascinat[ing],” “weird”, and “strange”. Several students strongly stated that they “loved” the hominid skull inquiries. This positive and emotive language was expressed a total of 62 times during the hominid skull focus groups, compared to 19 times during the extant skull learning experiences. The hominin skull learning experiences may have engendered more interest than the extant skull learning experiences, or may have built upon the motivational momentum already created by the extant skull inquires.

Students shared various reasons to explain their positive attributions to the hominin skull learning experiences. Most of these explanations related to the interesting knowledge they gained. Students thought it was “weird” or were “surprised” that the hominin skulls “look so similar to humans”. Others thought it was “cool” that other hominins like “Neanderthalensis and

Homo floresiensis lived at the same time as us...but they still went extinct and we lived on”.

Other students found it “interesting” to see “how one evolved into the other”. Several students specifically mentioned the Hominid Hallway Phylogeny learning experience. They explained that it was “interesting to see how they [hominids] kind of relate, and how they have similarities and differences, yet could be more chimpanzee or human-like”. Another student expressed awe regarding evolutionary time. He exclaimed, “But to look back six million years ago. It’s kind of like wow!”.

The pervasive use of this positive, emotive language may have suggested that the hominin skull learning experiences a) sparked situational interest, and b) engendered intrinsic motivation. Situational interest may have been sparked based on student expressions such as surprise. Inciting situational interest is important to hook student interest, especially when students have minimal background knowledge of the given topic (Hidi & Harackiewicz, 2000), such as the topic of human evolution. However, the motivation to learn may have been ephemeral, because expressions such as “weird” or “strange” may not have indicated a personal need for additional inquiry. On the other hand, the descriptive language used by focus group participants may have been an outgrowth of intrinsic motivation, because this language could have arisen out of experiences of enjoyment, interest, and excitement. And such experiences often create an intrinsic need for more of these same experiences (Deci, 1992; Dewey, 1938). Moreover, coupling emotive language with knowledge learned may have indicated that students adopted a mastery goal orientation (Hidi & Harackiewicz, 2000; Pintrich, Marx, & Boyle, 1993). Students who adopt a mastery goal orientation become focused on knowledge, learning, and understanding and are often motivated more intrinsically (Hidi & Harackiewicz, 2000; Pintrich, Marx, & Boyle, 1993).

Situated learning.

Several student comments suggested that the hominid skulls learning experiences created a situated learning environment (Lave & Wenger, 1991), which can engender intrinsic motivation (Cordova & Lepper, 1996). Student participants suggested that learning experiences were contextualized through the habits of mind that were encouraged, couched in the discipline of paleoanthropology, and marked by “hands-on” experience and real world application.

One student-participant “loved” the hominid learning experiences, not because of the interesting knowledge gained, but because of the scientific habits of mind that were nurtured. She explained,

I absolutely love to think outside of the box, and still have that curious mindset about things. So, I love to think about how this [hominin] could have gone extinct, making more inferences about all the characteristics of the skulls, and thinking about the future. You could just go beyond and beyond and just keep going about all of your ideas about the topic and I just really enjoyed learning about it.

In this excerpt, this student-participant referenced the ability of the hominid skulls to stimulate creativity and divergent thinking, an important characteristic of science (Chiappetta & Koballa, 2004), and an indication that the hominin skull learning experiences challenged students to emulate the thinking of scientists. This excerpt may have also suggested that the hominin skull learning experiences enhanced her “need for cognition” a component of motivation (Dole & Sinatra, 1998, p. 119).

Three students expressed appreciation regarding an authentic learning environment couched in the discipline of paleoanthropology. One of these students gave the entire unit a “thumbs up because we really got to learn what paleoanthropologists do, and discover fossils to

study them, and to learn ...more about evolution”. A second student insinuated that these learning experiences were practical to the real world because “it’s [the hominin skull learning experiences] useful...[and] we got to work on stuff that could really help us in the future...deciding what career we want to work on”. Two other students applauded the unit because it was “hands-on,” meaning there was an emphasis on action and doing.

These statements may have suggested that learning experiences helped students make connections to the discipline of paleoanthropology, to real world phenomena, and to the practices of paleoanthropologists. Such contextualization during learning may have enhanced intrinsic motivation to learn (Cordova & Lepper, 1996).

Enhanced perceptions of competency and knowledge.

Students perceived that their competencies and knowledge increased during the hominin skull learning experiences. And, the perceptions of increased competency and knowledge are components of motivation (Hidi & Harackiewicz, 2000). First, students-participants expressed that their competency to observe was increased through the use of the 3-D skulls. Sixteen students suggested that the hominid skulls made learning easier because they were “helpful”, enhancing their abilities to observe through their sense of sight and touch. For instance, one student explained, “you can observe all you want” and “see it from different angles”. Another student specifically noted the use of the sense of touch. “We had *Homo neanderthalensis* and on the top of its head, there were small holes. And we really didn’t see them or really know what they were until we were feeling it”. So, students perceived that the presence of the hominid skulls allowed them to observe more effectively.

Second, student-participants (n=11) expressed that they perceived that they “learned so much information”. One student went into more detail, explaining that the hominid skulls lessons

makes you understand a lot about evolution...and you learn big words like sagittal crest.

Like I didn't know if anyone said prognathis[m] before, I wouldn't have understood anything they meant. Or if they said brow ridge or diurnal, I wouldn't have understood what diurnal was. And foramen magnum, I would not have [had] a clue what that was"

These students perceived that they gained knowledge that they did not know before.

Perceptions of increased competency and knowledge are important components of motivation, particularly important for fueling intrinsic motivation (Hidi & Harackiewicz, 2000; Pintrich, Marx, & Boyle, 1993), which can then play into the degree of student engagement and conceptual change (Dole & Sinatra, 1998).

Privileged access.

Four students recognized the privileged access they had to the skulls, saying "...this was extremely fun, because we got to work with skulls, and I think we were the only class in the whole school that got to do this." Statements such as this may have suggested that students perceived learning experiences as meaningful, which is an indication of intrinsic motivation (Hidi & Harackiewicz, 2000).

Novelty, shock, and disgust.

Students referenced novelty (n=3), expressed shock (n=1) and expressed disgust (n=1), which may have indicated that learning experiences created situational interest to learn (Hidi & Harackiewicz, 2000). One student referenced novelty, saying, "...we've most likely never discovered or learned this before". One student expressed initial shock of the 3-D hominid skulls. "At first it was a little bit, what in the world are they doing here?". This student changed her tune, however, after the learning experiences. She said, "...once we started talking about them it was pretty cool because you got to learn about...*Homo sapiens*". One student expressed disgust

of the hominid skulls. “They are kind of ugly”. Shock and disgust were not necessarily negative indicators. They may have served to “catch” and “hold” (Dewey, 1913) student interest. The combination of these smaller indicators of motivation, may have sustained situational interest long enough, to then engender intrinsic motivation to learn (Hidi & Harackiewicz, 2000).

Making connections with current research.

Several important articles have been published since my data collection (e.g., Smith 2010a, 2010b, Rosengren, Brem Evans, & Sinatra, 2012; Southerland & Nadelson, 2012). The comprehensive literature reviews of Smith (2010a & 2010b) suggested that the science education field was wide open in suggesting empirically based pedagogical methods for supporting affect during evolution instruction. Nadelson & Southerland (2012) answered Smith’s call for research in this area, proposing an “intentional conceptual change” approach (p. 358). My own findings add to this current research and discussed. The use of 3-d hominid skulls in a situated, inquiry-based learning environment enhances affect. I go into more detail about advancements in evolution education research below, and juxtapose my own findings with these advancements.

One commonality with recent evolution education research has emphasized that teaching and learning consider the learner (affective domain) in addition to the delivery of a strong cognitive message (Smith 2010b; Southerland & Nadelson, 2012). Smith (2010b) explained, “it is my opinion that the largest barriers to studying and learning about evolution are the philosophical and religious issues involved (p. 561). One of his solutions recommended that future research use Dole and Sinatra’s (1998) cognitive reconstruction of knowledge model as a framework for curricular design and assessment—as the model highlights the interdependency of the learner and message in determining overall engagement for learning and conceptual change. However, Smith’s review (2010a & 2010b) did not give many pedagogical suggestions to

address the affective domain of learning with secondary students. His suggestions to teach the NOS in tandem with evolution content seemed to be more about developing cognition. And, his final recommendations to “be respectful of your students”, “be clear”, avoid “debates”, “be careful that your own personal beliefs don’t seep into your instruction”, and “be gentle and patient”, were intended more for the teacher than the learner (p. 565). So, as of 2010, the need for empirically based studies regarding affect and evolution pedagogy was ripe with opportunity. I think my study data/study provides viable pedagogical approaches for addressing affect in terms of the learner.

Another set of researchers, Southerland and Nadelson (2012), have answered Smith (2010b) in their book chapter “An Intentional Approach to Teaching Evolution: Making Students Aware of Factors Influencing Learning of Microevolution and Macroevolution”. Southerland and Nadelson (2012) challenged graduate students to reflect directly, explicitly, and intentionally on their epistemological beliefs, affect, and learning dispositions throughout evolution learning. For instance, one of the first learning experiences had students study Dole and Sinatra’s (1998) CRK model, and then use this as a framework to make connections with their affective responses during learning. Participant understanding and acceptance of evolutionary theory increased based on post assessments. I think that my research study has provided another empirically based pedagogical strategy to teach evolution and regarding affect.

I like returning to Smith’s (2010a) comment, “Too often instruction has provided meager empirical evidence such as measuring parts of skulls, fossils, etc.” (p. 526). I challenge Smith’s comment in two ways: 1) fossil hominid skulls provide ample evidence for both micro and macroevolution, and 2) fossil hominid skulls incite enough situational and intrinsic motivation to learn, propelling students past the religious and philosophical barriers they bring to learning. I

addressed the first of my challenges later in this results section (Cognitive Outcomes). However, I think the discussion of focused codes that transpired earlier (i.e., a) positive emotive language, b) situated learning, c) enhanced perceptions of learning, d) privileged access and novelty) provides evidence behind my claim that hominid skulls enhance affect. Smith (2010a & 2010b) clearly made an unfounded claim about the effectiveness of fossil skulls. And, learning tools (centerpieces for inquiry such as skulls) can condition affect toward subsequent cognitive function, in addition to other methods such as Southerland and Nadelson's intentional conceptual change pedagogical approach. My claim that hominid skulls enhance affect, is not unique (e.g., Gipps, 1991; Nickels, 1987). However, a unique contribution of this study is the empirical, student-generated evidence revealed to support such a claim.

The next section will focus on the cognitive outcomes of the hominin skull learning experiences.

Cognitive Outcomes.

Cognitive outcomes: What students learned that they did not know before.

During one post focus group interview, I asked the question, "What have you learned that you did not know before?". I asked this question to get a sense of whether there were any cognitive changes incurred due to the hominin skull learning experiences. One focus group was asked this question (n=6), serving as a sample of all focus groups. I should have asked this question during all the focus group interviews, because of its direct nature to cull cognitive change due to my curricular intervention. Several student-participant comments outside of this one focus group were included in this section, however. These student-participants explicitly stated that they learned something they had not known before. Table 4.23 organizes what

students thought they learned that they did not know before. The following student, expressed most of the data outcomes in Table 4.23, but in one interview response:

I thought it was interesting...to learn that all these different types of skulls...and three other types besides *Homo sapiens* were alive at the same time. It was interesting to see how many compared to humans were actually alive at once. And there was only one of us. But it's kind of cool to see your ancestors. And, we actually learned how it's like humans evolved from humans and there's the missing link between gorilla's and apes and humans. But so far, it just looks like we evolved from ourselves. It's interesting to see how they evolved over time, different skulls.

I thought it interesting, that most responses in Table 4.23 indicated that students learned about hominin diversity, “that there were...many different kinds of humans”.

Table 4.23

What Students Learned about Hominins that they did not Know Before

Cognitive change	hominin diversity	• There are a lot of species of extinct homin[ins]. • I had no idea any of these [hominins] actually existed. • Before we learned this, I thought the only human was <i>Homo sapien</i>. But then when we learned more about it, I learned about the different species...I learned that they're all humans too. Because they all share the same characteristics. • I've been calling ourselves <i>Homo sapiens</i> [instead of] humans, because there are so many species of humans that [the word human] that's not specific enough. • Well, I didn't even know there was any of these creatures or species whatever you want to call them. I just thought it was humans and there was gorillas and that was it. I realize there was all these different species that I never knew about. • I didn't hardly know it all that there was that many different kinds of humans like I knew there was Neanderthals but that's the only kind that I actually really knew. And then I found out that there was maybe like the <i>Homo erectus</i>...and I was like wow! What is that? I didn't know at all and I was really surprised by that. • ...before we did this, I didn't think there [were] any other species of humans besides humans [like the] Neanderthals and <i>tchadensis</i>.
	shared derived characters	• What I found interesting was the teeth. Because I didn't think that, because the farther back we went and discovered on the time line of the skulls, you realize that most of them have the same teeth pattern. And have the same number of teeth. But once you get quite far back, like six or seven million years, it changes. So I just thought that was really interesting. Because I wouldn't think that, I would think that over time they probably wouldn't have the same teeth or teeth numbers as us, but I guess they do still...[the teeth number] was over two-one-two-three.
	NOS or nature of paleo-anthropology	• And then, now my understanding is that, uh, there are so many different types of science that it's almost impossible to count how many types there are. And it's so diverse that it is, it's insane, I guess. • ...how many pieces it took to put the fossil together. • How many different species they have uncovered from all those years ago.
	human evolution	• I agree with [fellow classmate] because the last or the part of the interview that we had, I thought, I wasn't exactly sure where I stood on that question. But now that we actually got to see the timeline and we actually got to layout what, what was when. It sort of makes more sense that we wouldn't evolve from monkeys. Because as he said, we more evolved from humans. And, the chart that we had found so far and all the fossils conclude that, the evidence that we have right now says that we have evolved from more human type creatures.
	accepting evolution	• I didn't believe it [before], but by looking at them it looks like a really close possibility...that we could have evolved.

The hominin skull learning experiences may have been most effective at communicating the fact that we have a rich and diverse human past. And by recognizing the diversity of our human evolutionary past, students may then see that “by looking at them it looks like a really close possibility...that we could have evolved”.

Cognitive outcomes: Responding to common misconceptions.

I was able to compare pre and post focus group data regarding two common alternative conceptions: a) Humans evolved from monkeys, and b) Evolution is *just* a theory. I asked students to comment on these two statements during both the pre and post focus group interviews. I wanted to see if the hominin skull learning experiences helped to confront these

alternative conceptions, which may be barriers to learning normative views of evolution (Smith, 2010b). I hoped that during the post focus group interviews, student-participants would disagree with both statements and approach a more normative explanation.

Pre and post data regarding these two statements were compared in two ways: a) comparing overall pre focus group to post focus group interview data, similar to summary statistics (Tables 4.24 and 4.26), and b) comparing pre individuals to post individual views to gain specific examples of change (Tables 4.25 and 4.27). For reporting overall data results (Tables 4.24 and 4.26), I used the same coding scheme as developed during the coding of the pre focus group data. Markers in tables 4.24 and 4.26, however, represented comments from post interviews (except when there were no post interview responses codified in a particular initial code). For instance, there were no post interview comments expressing agreement with the statement, “Humans evolved from monkeys”. Markers used to demonstrate this code were from pre focus group interview data.

Tables 4.25 and 4.27 reported pre and post interview data dealing with the statement “Humans evolved from monkeys”. I was pleased by the post focus group data. Fifteen out of 15 participants (100%), disagreed with the statement, “Humans came from monkeys”; only 38% of students (5 out of 13 participants) disagreed with this statement pre-intervention. Also promising, thirteen of the fifteen post student participants expressed more normative thinking. They were able to justify their reasoning, which may have indicated that they were also developing understanding (Smith & Siegel, 2004).

Three individuals (Students A, B, and C in Table 4.21) served as a sample to demonstrate how an individual student-participant changed his/her view regarding the statement “Humans evolved from monkeys”.

Table 4.24
Post Focus Group Data: Responding to “Humans Evolved from Monkeys”
(n=15)

Focused code	Initial code		Pre n=13	Post n=15	Marker
Responding to “Humans evolved from monkeys”	Showing agreement	Alt. concep.	15%	0	There are a lot of similarities between them. Like the gorillas and humans and stuff. So there’s a lot of evidence to support that we did evolve from them [monkeys].
		Blend	46%	0	I think we did evolve from apes. Maybe apes evolved and not monkeys, because they are more similar to us, like chimpanzees and stuff.
	Showing disagreement and alt. and norm. conception	Blend	23%	13%	Cause first of all monkeys are present day. So...humans didn’t come from a present day animal. And second of all, monkeys aren’t really related to humans and apes. And there again, the apes are like present day. So they [humans] wouldn’t have evolved from it [apes]. So, I don’t think the humans could have come from monkeys, cause they are really in no way related.
		Norm. concep.	15%	87%	I agree with [classmate], because the last...interview that we had...I wasn’t exactly sure where I stood on that question. But now that we actually got to see the timeline and we actually got to layout what was when. It sort of makes more sense that we wouldn’t evolve from monkeys. Because as he said, we more evolved from humans. And, the chart that we had found so far and all the fossils conclude that. The evidence that we have right now says that we have evolved from more human type creatures.

Table 4.25
Tracking Student-participant Change: Responding to “Humans Evolved from Monkeys”

Student	Pre student response	Post student response
	Pre student initial code	Post student initial code
A	They might have evolved from monkeys because we evolved from like gorillas...and monkeys could have been ancestors of like gorillas. I think since monkeys and humans are both primates, they are like our ancestors.	I think...monkeys are present day living creatures so are the humans, but a species can’t evolve from a present day species. Scientists state that humans evolved from an extinct hominid species.
	Agreement, alternative conception	Disagreement, normative conception
B	I think it’s a possibility because our bone structures are so alike...So, it’s extremely possible for us to have evolved from apes and primates.	We came from other humans way back until we get to the missing link or a common ancestor with apes and then we go from there. But we haven’t found the missing link yet so we don’t know exactly where we came from. Except from other humans.
	Agreement, blend	Disagreement, normative conception
C	There’s a lot of similarities between them humans and monkeys. Like the gorillas and humans and stuff. So there’s a lot of evidence to support that we did evolve from them.	We came from...one of these skulls...[one of these] <i>Homos</i> .
	Agreement, alternative conception	Disagreement, normative conception

Post interview responses also indicated that students were using the language of scientists. (i.e. contemporary, common ancestor, hominids, evolutionary tree, bipedally).

- We evolved from other **hominids** and not monkeys. We couldn't have evolved from monkeys because monkeys were alive at the same time as us...and there's not really any resemblance. Humans don't have tails. Monkeys can't usually walk bipedally.
- Humans can't have come from a **contemporary**. So they may have had a **common ancestor** because they do [humans and monkeys] have similarities.
- ...They [monkeys] are just cousins on the **evolutionary tree**.

Student language steeped with scientific vocabulary and applied in context may have indicated that students participated in a community of practice (Lave & Wenger, 1991).

Also important to note, some students showed a blend of both alternative and normative conceptions. These findings support contemporary views of conceptual change (Dole & Sinatra 1998; Sinatra, Brem & Evans, 2008; Strike & Posner, 1992). Learning does not occur in a neat progression from alternative to normative conception. Students are more likely to move along some sort of bumpy cognitive trajectory.

Table 4.26 compared pre/post student responses to the statement, "Evolution is just a 'theory'", also a common alternative conception that forms a barrier to learning normative views (Smith, 2010b). An analysis of this data was messy, given how students used the term "theory" in different ways. Some students used the term in a normative way. Others conflated the term with guess, inference, idea, or tentative. The colloquial use of the term "theory" continued post intervention in spite of my efforts to clarify the scientific use of the term during teaching and learning. I put quotes around the term theory any time I interpreted its meaning to be a guess, and no quotes around the term if it I perceived it was being used in a normative way.

Table 4.26 Post Focus Group Data: Responding to “ <i>Evolution is Just a ‘Theory’</i> ” (<i>n=18</i>)					
Focused code	Initial code		Pre n=13	Post n=18	Marker
Responding to “evolution is <i>just</i> a ‘theory’” Evolution is...	not empirically based		21%	0	...I mean, anything could have happened. We weren’t really there to remember and write it down, so we’re only using guesswork.
	a theory (i.e. explanation)		0	17%	- I think evolution is true because it explains in detail how they change and why they change. And it actually makes sense. And there is no other explanation of why and how organisms change to better adapt. So it’s like pretty much the only thing you can go with. ...it’s like the most reasonable way to explain how things change from like millions of years. - Evolution is a concept that explains how living things came to be today.
		but tentative	0	6%	Evolution is a very good way to explain how things change, but scientists are still missing certain stuff to prove it.
	empirically based	but tentative	15%	22%	There’s a lot of proof that it [evolution] could be true, but then again we weren’t there. We can’t just sit there and watch species evolve to like another species, and then we get Lucy, and then watch her become human all of a sudden. It happens over time and they just found their skulls, and we sort of assume that even though we have a lot of proof that it did happen. So we can’t be 100% positive, but it’s very likely it [evolution] did happen.
		(fact/ proof/ observation)	23%	22%	Scientists know about evolution based on evidence. Well, when you say evolution is just a “theory”, like it’s kind of more than that. Its ways to link back how we came to be and it [evolutionary theory] came from observations and how scientists infer that we evolved....
		and “theory” (guess, idea, inference, tentative)	31%	33%	Evolution is a “theory”, but it is based on mostly observation. Scientists can’t prove that evolution exists so it’s <i>just</i> a “theory”. Because they can only provide evidence.
		but religious influence	15%	0	I think it is sort of truth, but we can tell from our evidence that they’re related [fossil skulls and extant skulls]. But because of the controversy over religion and how God put the animals on earth, people don’t want to accept that. But at the same time, we have facts and then you have religion and they are supposed to be separated...

Slight cognitive inroads may have been made, even though students continued to conflate the term theory with terms and/or meanings such as guess, idea, inference and tentative. First, three students pre-intervention stated that evolution was not empirically based. This notion was not expressed post-intervention. Two students fused religious content into their response pre-intervention. Religious commentary did not occur post intervention, perhaps an indication that students had a better grasp of the boundaries of science. Even more importantly, the number of participants who explained that evolution was an explanation (e.g., “the most reasonable way to

explain how things change from like millions of years”) increased from zero to three. I was pleased to see that these students were recognizing the theoretical place of evolutionary theory, going beyond just giving a simple definition of the term.

In addition, initial codes of “tentative” increased pre to post intervention. This may have indicated that the hominin skull learning experiences may have relayed this characteristic of the nature of science (traced back to the use of Piltdown man and phylogenies as pedagogical techniques to relay this characteristic). This may have indicated that students were developing a healthy dose of skepticism, also an important feature of science. However, it may have also meant that students were using the notion of science as tentative, as a means to also view science as just a “theory”. For example, one student explained, “Evolution is just a ‘theory’ because it is an idea or inference that could possibly be changed in the future”. Future research might need to address how to relay the idea that evolutionary theory is tentative, but not just a “theory” as in the colloquial use of the term. Also common in post focus group responses was the use of the term “proof” in the place of evidence, data, or observation, which is problematic in post-positivistic circles and contrary to the tentative nature of science.

Three individuals (Students D, E, and F in Table 4.27) served as a sample to demonstrate how an individual changed his/her view regarding the statement “Evolution is just a ‘theory’”.

Table 4.27 <i>Tracking Student-participant Change: Responses to “Evolution is Just a Theory”</i>		
Student	Pre student response	Post student response
	Pre student initial code	Post student initial code
D	Things like humans evolving from gorillas cannot be based on observation, because we can't look back before our time. Evolution is just a “theory”, but it could very well be true.	There's a lot of proof that [human evolution] could be true, but then again we weren't there. We can't just sit there and watch <i>tchadensis</i> evolve to like another species, and then we get to Lucy, and then watch her become human all of a sudden. It [human evolution] happens over time, and they just found their skulls. And we sort of assume that even though we have a lot of proof that it did happen. So we can't be 100% positive, but it's very likely it did happen.
	not empirically based	Empirically based and tentative
E	That part is true, because it is an idea but they have found a lot of facts on that idea. And using radioactive dating, and then finding fossils, they could support that really heavily...	I think it was just a “theory” a long time ago, but now they have found a lot of fossils and carbon dated it. So I think it's grown to be more than <i>just</i> a “theory”. Evolution is a concept that explains how living things came to be today.
	Empirically based and “theory”	Empirically based and theory
F	I think [it] is partly a “theory”, but it's partly the truth, because some animals like you can tell they...definitely have ancestors, and so you know they definitely came from that animal and have evolved...but it could be a theory or it could be a fact.	I think [evolution] is more than a “theory” because they have proof that certain things are related to...present day organisms. So you can't really say it's a “theory” if they have proof. Because they can tell you and they can show you that things have come from other organisms.
	Empirically based and “theory”	Empirically based

Students D, E, and F in Table 4.27 served as samples to demonstrate the slight cognitive inroads that may have occurred because of the hominin skull learning experiences. Student D, for instance, may have discovered that historical non-demonstrative evidence is valid. Pre intervention, Student D expressed the alternative conceptions that “humans evolving from gorillas cannot be based on observation”. Yet post intervention, Student D stated that there is a “lot proof that [human evolution] could be true”, citing “*tchadensis*” and “Lucy”, but also noting the tentative nature of science. Student E improved conceptually by also noting that evolution is “more than just a theory” and an explanation, two notions that were not expressed pre

intervention. Student F made similar improvements as Student G in regards to referencing theory in a more normative sense, rather than just an idea.

These findings have influenced my thinking. First, I was pleased to see some conceptual movement from students, given the difficulties of teaching evolution and the nature of science (Shtulman & Calabi, 2012; Smith 2010a & 2010b). And, perhaps it is a success that my students were simply engaging in a relevant conversation, also occurring in the general public. Also, these findings may not be too surprising when reflecting on Dole and Sinatra's (1998) CRK model. Conceptual change regarding the understanding of "theory" may have been weak, given the "strength" and "coherence" of the everyday use of the term, and students' commitment to the colloquial use of the term (Dole & Sinatra, 1998, p. 119). But, pedagogical modifications need to be made. I have concluded that I need to develop more explicit learning experiences to challenge students to compare and contrast the use of the term "theory" in colloquial versus scientific contexts. The relationships between theory, observation, evidence, inference, and proof should also be addressed explicitly.

Tables 4.28 and 4.29 compare pre and post focus group interview data addressing with the focused code, "Contemplating evolutionary time". Post interview, I asked student-participants, "How long does evolution take", often followed by a more specific question such as, "How long does evolution take, such as the evolution of *Homo ergaster* to *Homo sapiens*"? The post interview data showed cognitive improvement. Eighty percent of student-participants (n=18) post interview expressed that evolution takes either thousands and/or millions of years to occur, in comparison to only 38% pre interview.

Table 4.28

Post Focus Group Interview Data: Contemplating Evolutionary Time

(n=24)

Focused Code	Initial Code		Pre n=21	Post n=24	Marker
Contemplating evolutionary time	Less than thousands of years		29%	0%	Like with the peppered moth, it [evolution] didn't take thousands of years. Like it happened really quickly. So, it [evolution] doesn't always take a long time.
	Thousands or millions of years	Thous.	24%	13%	I think <i>Homo floresiensis</i> [was] around 18,000 years. And <i>Homo neanderthalensis</i> [was] around 60,000 years.
		Thous. and millions	0	29%	Some of them can date back to like six point one million years like the <i>tchadensis</i> . But like the <i>neanderthalensis</i> is only a few hundred thousand years old. The same going up all the way to <i>Homo erectus</i> . But then when you get to Lucy it starts going into the millions. All the way back to six million years ago. Which is a pretty long time.
		millions	14%	38%	<i>Tchadensis</i> or Lucy are millions of years old. Lucy is 3.2 million years old, and <i>tchadensis</i> is 6.7 million years old. So between them and humans is a really long period of time.
	Dependent on...	degree of change	0	4%	It [the time it takes for species to evolve] depends on the change. For like it was a slight change maybe like skin color, that might take a less amount of time compared to like the evolution of humans from Lucy, where there might have been such a huge difference it could take millions of years. But whereas if you wanted to do the peppered moth example, that took a hundred [years], so it depends on the change and the complexity of the animal.
		environment	0	4%	I think you would have to know... what was going on at that time and knowing if there was lots of floods, if there was a drought, and it really affects how short and long [evolution] takes.
		reproductive cycle	19%	8%	It [evolution] might take a longer or shorter amount of time. It might take longer... depending on the life span of the organism because the peppered moth, they might not live as long as a human. Only a couple of the generation would only last every so few years. And then after that generation, then to new generation would come with better adaptations.
	A long time		14%	0%	[The evolution of the woolly mammoth takes] lots of lifetimes cause you have the one organism that won't survive so you have to wait till he dies and then the ones that will survive they still have to pass on the genes [them]selves to be more genetic mutations, so they'll all the way get up to they have a lot of fur and stuff. So it will take a long time.
		and "recent"	0%	4%	...if we look at it on the hominids scale, then it goes back a long time, but if you look at it like from everything, there's a lot like hominids are pretty recent even so.

Other changes were more subtle. For instance “Student D” in Table 4.29, made a similar response when discussing the nature of evolution as a theory, but changed “thousands” to “millions” when noting evolutionary time. Changing “thousands” to “millions” may have been influenced by the study of hominins, the oldest which dates back to millions rather than thousands of years ago. Also an improvement, students used more scientific language in post

interview responses and were able to more often discuss evolutionary time in the context of specific species, such as in the response of student H (Table 4.29).

Table 4.29 <i>Tracking Student-participant Change: Evolutionary Time</i>		
Student	Pre student response	Post student response
	Pre initial code	Post initial code
G	I think that would be a very false statement cause evolution to me I think is a very good way to explain how organisms change. From thousands of years.	I would say it's not a theory. Cause it's like the most reasonable way to explain how things change from like millions of years.
	Thousands	Millions
H	It depends on how drastic the change in the trait is. Like if it's going from huge teeth of the saber tooth to the tiny teeth of the animals right now it might take thousands of years. But if it's a small change by centimeters, it might just be a few generations.	Some of them [hominins] can date back to like six point one million years like the tchadensis. But like the neanderthalensis was alive when we [Homo sapiens] were and is only a few hundred thousand years old. The same going back to homo erectus. But then you get to Lucy it starts going into the millions all the way back to six million years. Which is a pretty long time.
	Less than a thousand	Thousands and Millions

Students (n=4) continued to reason that the pace of evolution was also dependent on certain variables. Four students pre interview explained that the pace of evolution was dependent on a species' reproductive cycle. Two students post interview also shared this explanation. However, post interview, two new initial codes emerged: the pace of evolution depends on the a) environment, and b) degree of change. The pace of evolution depends on the environment, such as the presence of floods and drought. And the pace of evolution depends on the degree of change, because "a slight change maybe like skin color, that might take a less amount of time compared to like the evolution of humans from Lucy, where there might have been such a huge difference, it could take millions of years". So, I was pleased that student-participants considered macroevolutionary time, and broadened their view of the variables that influence the pace of evolution. This finding may have suggested that students were grasping deep time, a component

of macroevolution which researchers have suggested should have more emphasis in evolution education (Catley, 2006; Smith, 2010b).

Cognitive outcomes: Inquiry.

The post interview data suggested that students were engaged in inquiry. This data suggested that the hominid skulls helped students engage in the essential features of inquiry (NRC, 2000, p.29). Students: a) engaged in scientifically oriented questions, b) made observations and inferences (i.e., formulating explanations from evidence), c) gave priority to evidence, and (d) communicated and justified explanations (NRC, 2000, p. 29)

Like the extant skull learning experiences, students continued to engage in scientifically oriented questions or pose their own. Daily essential questions posed by myself as the teacher, framed each learning experience (Table 3.1). However, students consistently posed their own scientifically oriented questions. This became evident during post focus group interviews, and was corroborated through student work samples and the extinct skull presentations discussed earlier in this chapter.

During the post focus group interviews, thirteen focus group student-participants posed scientifically oriented questions. I emailed a sample (n=5) of these questions to Dr. René Bobe, associate professor of anthropology at George Washington University. Dr. Bobe often goes on safari to the Afar region of Ethiopia and Kenya, unearthing hominin and extinct mammalian fossils to reconstruct paleo climates and ecologies. Table 4.30 shows a sample of student questions posed during the focus group interviews, and Dr. Bobe's response to each (R. Bobe, personal communication, September 18, 2012).

Table 4.30 <i>Student Generated Questions: Responses from Dr. René Bobe</i>	
Student question posed	Dr. Bobe's response
I did wonder why the size fluctuated. Because I didn't really understand if they [hominins] were just evolving, changing over time, why would they go small, big, big, small, big, and then end up looking like a human skull.	"Changes in body size occur fairly easily in many lineages, sometimes as a response to environmental changes. This is indeed a current topic in paleoanthropology. Under what conditions can we expect body mass to increase, or decrease?"
What was the surviving characteristic that we have that let us not go extinct?	"Important question, and a current one. Very likely there is no single characteristic, but a suite of characteristics that have allowed our species not just to survive, but to expand over much of the terrestrial landscape."
Why did the other species [hominins] go extinct?	"Extinction is a fact of life, and most species go extinct. This is also an important and current question, and one for which we have mostly speculative answers."
It makes you wonder why was their (<i>Homo neanderthalensis</i>) brain case so large.	"Another very good question, one that is still generating quite a bit of scientific debate. Overall robusticity and/or cold adaptation are among the plausible answers."
I would like to know their DNA structure.	"Progress is being made on this front as we sample more individuals."

The data in Table 4.30 represented several positive cognitive outcomes. First, student participants posed scientifically oriented questions--capable of being answered through scientific processes. More impressive, these students asked similar questions being asked by the paleoanthropological community, suggesting that the hominin skull learning experiences created an authentic learning environment and nurtured a community of practice (Lave & Wenger, 1991) (i.e., student-participants engaged in the conversation and practices of paleoanthropologists). It is interesting to note that no student participants posed any religious questions during the post interview process. They may have understood the boundaries of our science classroom, perhaps established by our NOS unit, or may have been intimidated to raise such a questions.

Student work samples corroborated the claim that students engaged in scientifically oriented questions. During the extinct skull learning experience 10, Independent Research,

students posed and researched a question they wanted to answer. The following is a list of the questions students researched for this learning experience (n=30):

- What kind of tools did Neanderthals invent or use?
- Why is *Orrorin tugenensis* called millennium man?
- Which common ancestor links gorillas and humans together?
- Where did *Homo erectus* live and what tools did it have and use?
- Where did *Homo floresiensis* live and what other organisms did it live with?
- How old is *Homo habilis*, and what do scientists think it looked like?
- When, where, and how was the first *Australopithecus africanus* found?
- Who is the Millennium Man? n=2
- When, where, and who was the *Sahelanthropus tchadensis* found?
- How long did it take scientists to come to the conclusion that Piltdown Man was a fraud? What does its name represent? Why did scientists create this fake skull?
- Who was Piltdown man? n=2
- What made *Homo floresiensis* go extinct?
- Why did Lucy go extinct?
- Why did *Australopithecus afarensis* go extinct?
- Why did *Paranthropus boisei* become extinct? n=2
- How did *Sahelanthropus tchadensis* become extinct?
- Why did all the other species in the genus *Homo* go extinct? n=2
- Why did *Homo neanderthalensis* go extinct? n=4
- How does *Homo neanderthalensis* compare to *Homo sapiens*?

- Does the level of intelligence differ between *Homo sapiens*, *Homo floresiensis*, and *Homo neanderthalensis*?
- How did *Homo floresiensis* relate to the modern humans and other species?
- Is *Australopithecus afarensis* [Lucy] more human like or chimp like?
- What are the characteristics of *Australopithecus afarensis*?

Out of thirty students who generated and investigated independent research projects, twelve students wanted to know why or how a particular hominin went extinct. Future pedagogy might build on this interest and help students realize that extinction is a common feature of macroevolution (Catley, 2006). Last, students also posed three scientifically oriented questions after they drew their extinct skull fossil find (Figure 4.3).

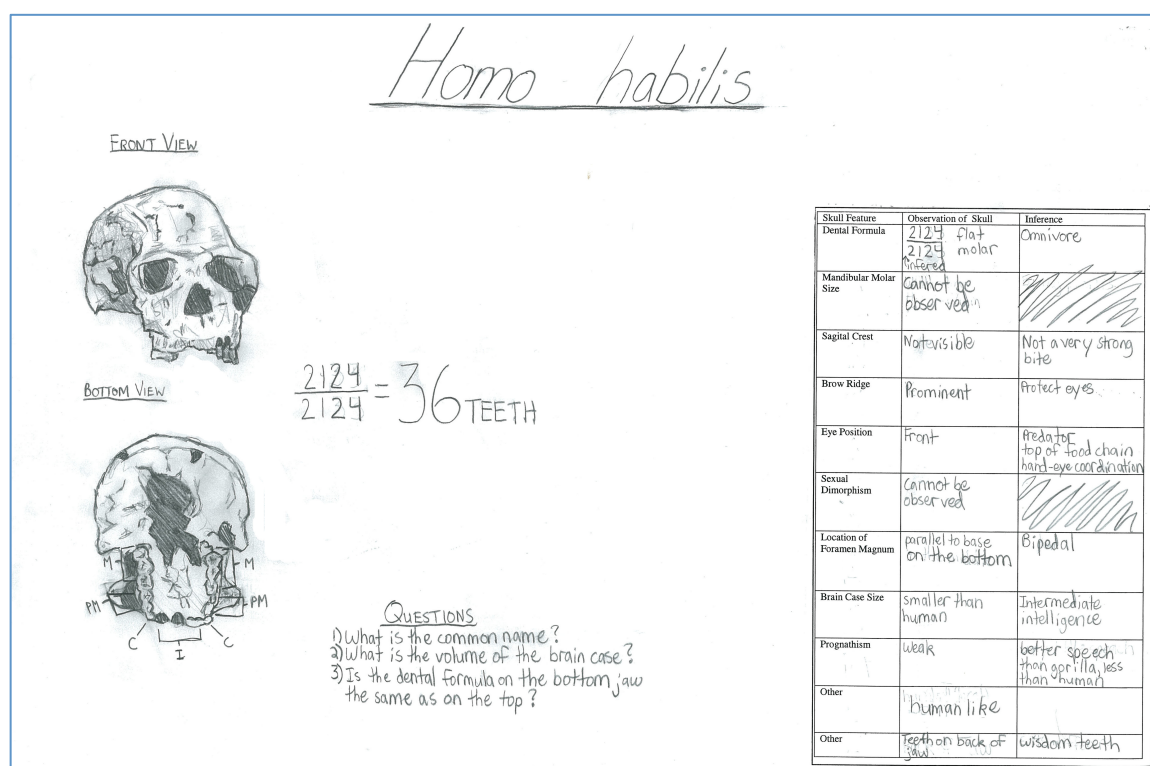


Figure 4.3. Extinct Hominin Skull Drawing and Obs./Inf. Chart. Student-participants created detailed drawings of their hominin skull fossil find, indicating the dental formula, labeling the teeth, filling out and observation and inference chart, and generating three questions for future inquiry.

Thus far, I have made the claim that students engaged in scientifically oriented questions as an essential feature of inquiry (NRC, 2000). Learners also gave priority to evidence in responding to questions and formulated explanations from evidence (or inferences from observations). Giving priority to evidence, and connecting explanations to this evidence permeated most of the responses to post interview prompts. Table 4.31 shows a sample of student responses to interview prompts, and how students linked evidence to their explanations.

Table 4.31 <i>Students Relate Evidence to Explanation and Give Priority to Evidence</i>	
Post interview prompt	Student response with evidence (in bold) and explanation (<i>in italics</i>)
How would you respond to the statement “Humans came from monkeys	<i>We came from...one of these skulls...[one of these] Homos.</i>
How long does evolution take?	Some of them [hominins] can date back to like six point one million years like the <i>tchadensis</i>. But like the <i>neanderthalensis</i> was alive when we [<i>Homo sapiens</i>] were and is only a few hundred thousand years old. The same going back to <i>Homo erectus</i>. But then you get to Lucy it starts going into the millions all the way back to six million years. Which is a pretty long time.
What do you think it means to be human	A human [is] bipedal, has eyes in the front, is diurnal, an omnivore, has a large brain case, dental formula 2123 over 2123...no sagittal crest and reduced brow ridge. Like the Neanderthal would be like human, and the boisei would not be human. Neanderthalensis is a human because it's prognathis. It's just more like human than most of the other ones. And it does' have a sagittal crest and the brow ridge is very pronounced. And the foramen magnum is where it should be if you are bipedal. And so it walks on two feet. And then the dental formula was 2,1,2,3 over 2,1,2,3.
What are the relationships of the skulls on the table	<i>I would change it [our phylogeny] a little bit [student refers to the phylogeny of skulls on the table]. I would put this kind [student picks up Homo neanderthalensis] like that [student places neanderthalensis laterally to Homo sapiens, but slightly behind in terms of time] because they were contemporaries at one point. And then, [this] right here [student picks up Homo ergaster and places it behind Homo neanderthalensis in terms of time] and then this one kind of in the middle [student places Australopithecus afarensis behind Homo ergaster in terms of time, but in the middle of human and gorilla]. And that one kind of in the middle [student places Sahelanthropus tchadensis behind Australopithecus afarensis as far as time, but in between human and gorilla], because these two [afarensis and tchadensis] behind they have similarities of...the human and gorilla.</i>
Which skull do you think is the “missing link”. Why?	<i>We think that tchadensis is a common ancestor between gorillas and humans because it shares all the common characteristics of both of them. And it's older, so it's had time to evolve to both. It's got [the] 2123 dental formula like humans. It's got a pronounced brow ridge like the gorilla, a smaller brain case size like the gorilla. Eyes in the front like both of them. And then a foramen magnum on the bottom like the humans.</i>
Why was Lucy such an important find	<i>Well why it's [Lucy] is so important is when they found it, it just looked like [a] modern day human. But it's because they found it so far back is that they were like wow. When [did] this happen or whatever? But you know...they found the knee right? Yea they found the modern looking knee but the knee locked so you could walk bipedally.</i>
If you could fast forward a couple of hundred thousands of years, how might humans be different than they are today?	<i>I don't think we'll ever in a 100,000 years go extinct because of the technology. Like before we had the predator-prey relationship. You could see that nature would just make the population go up and down and it would never increase like the human population is today. And that's [increase in human population] because of all the technology...and that [technology] would make us survive even longer and not change.</i>

Student practices of linking evidence to explanation (or observation to inference), was corroborated by student work samples. Students generated observations and inferences while drawing their extinct skull find, and completing the related observation/inference chart (Figure

4.3). Students also provided evidence for the hominid phylogenies they created (Figure 4.4). These work samples provide evidence that students were linking evidence to explanation and giving priority to evidence.

However, these work samples also exemplify how the practice of inquiry focuses on process rather than right answers. For instance, the dental formula of *Homo habilis* (Figure 4.3) is incorrect. This formula should be 2123/2123. However, this student made a reasonable mistake given that this skull sample was missing most of its teeth, and the dental formula had to be reconstructed based on skull indentions and other clues rather than actual teeth. Other mistakes occurred when the student constructed their hominid phylogeny (Figure 4.4). For example, evolutionary relationships should have been made using dotted lines to represent the tentative nature of the phylogeny. This mistake could be attributed to me as the teacher. I was also an early learner of developing phylogenies, and learned “dotted line” procedure through subsequent readings and coursework. Also, the divergence of gorillas and chimpanzees occurred too soon on the phylogeny when considering molecular clock evidence. This mistake is reasonable given that the evidence of molecular clocks was beyond the scope of our learning experiences. However, I could have told the time range of both the gorilla and chimpanzee split, so that they considered this data in the construction of their phylogenies.

Students also communicated and justified their explanations during the post focus group interviews, also an essential feature of inquiry (NRC, 2000). I discussed these results in the following section titled, *Cognitive outcomes: Understanding*, because justifying is one of the four criteria for understanding identified by Smith and Siegel (2004).

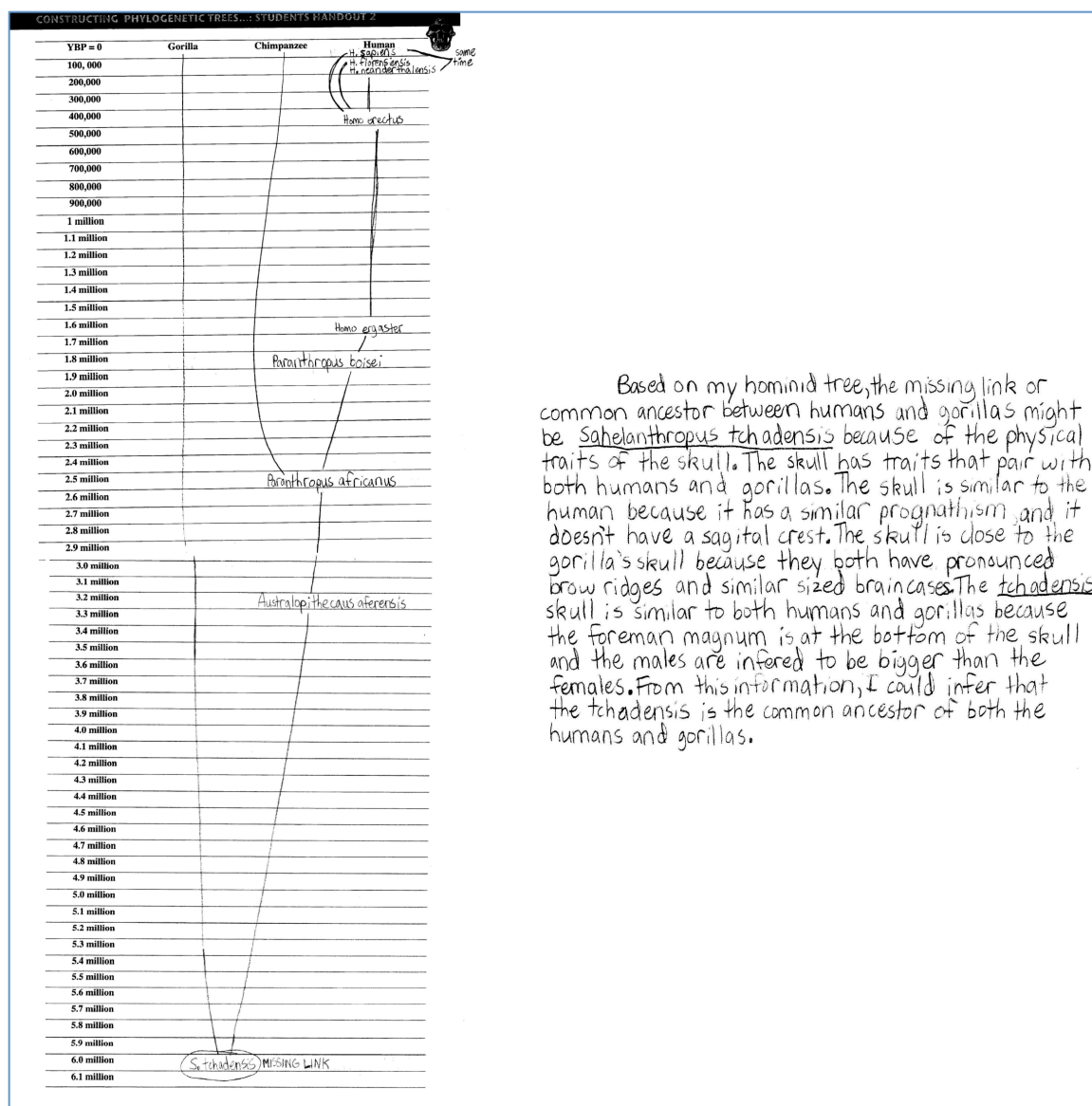


Figure 4.4. Student Work Sample of Hominid Phylogeny and Justification.

Cognitive outcomes: Knowledge

Students expressed that they gained knowledge during the hominin skull learning experiences. It was difficult to tease out student knowledge, as knowledge was fused into student excerpts in the affective section of this write-up, as well as in all the other major discussions in the cognitive part of this write-up. In Table 4.32, I report on knowledge unrelated to the

alternative conceptions discussed above, and on any other knowledge linked to understanding. For instance, the statement, “Evolution shows the change of a species into a different one over time”, was coded as knowledge, as conversation did not extend into application, justification, sense-making or making connections.

Table 4.32 <i>Knowledge Gained through the Hominin skull learning experiences</i>		
Expressing knowledge	Initial code	Marker(s)
	Evolution	• Evolution shows the change of a species into a different one over time. • Evolution is a very good way to explain how things change but scientists are missing certain stuff to prove it. • Evolution is a concept that explains how living things came to be today.
	Human evolution	• I would say that we inferred that we evolved from other hominins. • A lot of things change from like the more primitive hominids to the more recent hominids.
	Hominids/hominins	• The dental formula was like all the same for all of them [hominids]. And it was the same as humans, so that was interesting. • They [hominins] are similar because they all walked bipedally. And their eyes are basically in the same position. But, they might be different because the hominins that were older, they have more of a brow ridge or a sagittal crest. • <i>Homo neaderthalensis</i> had a bigger brain case size than <i>Homo sapiens</i>, but they went extinct before us. • I had <i>Australopithecus africanus</i>. And it took me forever to figure out how to say it. • I thought it was cool that some of these [hominins] actually lived during the human’s time, so we might have even interacted with them. • Looking at this timeline, it takes thousands to millions of years for these skulls to evolve and these species to evolve. • They [<i>Homo neaderthalensis</i> and <i>Homo floresiensis</i>] lived at the same time as us, ...but they still went extinct and we lived on. • Hominid is like a whole it’s kind of like not a species but a genus so it’s like a lot of different species like Neanderthal and <i>floresiensis</i>. But human is just like one species.
	“Missing link”	• The missing link is the ancestor between human, chimpanzees, and gorillas that connects all of them. • Nothing was really found before that old [referring to Lucy] and they were excited because they thought they had found the missing link because it had both ape and human qualities.

Cognitive outcomes: Demonstrating understanding

Demonstrating understanding: Making connections.

Students made connections during the post group interviews Table 4.33. The number of occurrences increased from 20 pre interview to 25 post interview. Students made connections as described by the following initial codes:

- Extant skull learning experiences (students realized that they were “extending” what they learned from the extant skull learning experiences. There was a relationship between what we came to know during the extant world and the extinct world.

- Paleoanthropology (students made the connection that reconstructing an entire extinct skull requires making inferences, because few skulls are discovered intact. Most have to be reconstructed using knowledge from multiple fossil samples and based on our understanding of bilateral symmetry, and
- Human evolution today (students connected hominin evolution learning experiences to everyday observations, such as the observation that “We’ve been getting taller and living longer, so that could be evolution”).

Table 4.33 <i>Students Demonstrating Understandings of Hominid Evolution through Making Connections</i>				
Focused code	Initial code	pre	post	Marker(s)
Making connections to	Extant skull learning experiences	20	25	Because a lot of the things with the extinct skulls we've learned with the extant skulls, we're just kind of extending with it.
	Paleoanthropology			Some of the parts [of the skull] are just inferences. They're added on, or were made to complete the skull.
	Phylogeny			• Mine [<i>Homo ergaster</i>] was pretty much like the grandfather of all the <i>Homo sapiens</i> and all the Neanderthals. I think it was the first <i>Homo</i> genus. • Um, well, they [hominins], most of them have the same dental formula. I thought that was pretty interesting. And, uh, their heads are kind of in the same shape. Some of them might be a little wider. But, they came from real common ancestors because they look so alike, most of them.
	Human evolution today			• Over the last couple of hundred years, we have been changing. We've been getting taller and living longer, so that could be evolution.

Students drastically increased the number of times they engaged in comparative anatomy during the post focus group interviews. This aspect of understanding increased from 5 to 31. Students made simple comparisons, such as noting the similarities and/or differences among hominins. Other students integrated the comparative anatomy process into broader conversations regarding evolutionary trends and what it means to be human, and/or justifying hominid phylogenies. I was pleased that students were engaging in comparative anatomy, as this activity is an essential feature of paleoanthropology (R. Bobé, personal communication, August 9, 2012), and thus indicative of students engaging in situated learning (Lave & Wenger, 1991).

Table 4.34

Students Demonstrating Understandings of Hominid Evolution through Comparative Anatomy

Focused code	Initial code	pre	post	Marker(s)
Making connections	Comparative anatomy	5	31	• Um, well, they [hominins], most of them have the same dental formula. I thought that was pretty interesting. And, uh, their heads are kind of in the same shape. Some of them might be a little wider. But, they came from real common ancestors because they look so alike, most of them. • We go back in time and as we go back in time like the brain case size and the skullsget smaller each time. And so they are adapting...their brain case size grows...for like more intelligence. • I would say <i>Homo erectus</i> [is human] cause if you compared it to the human they look extremely alike. Their brain case size is almost exactly the same. The prognathism is just a little bigger here like at the brow ridge. But otherwise they are exactly the same because their foramen magnum is in the same place and everything. • <i>Neanderthalensis</i> is a human because it's prognathism. It's just more like human than most of the other ones. And it does' have a sagittal crest and the brow ridge is very pronounced. And the foramen magnum is where it should be if you are bipedal. And so it walks on two feet. And then the dental formula was 2,1,2,3 over 2,1,2,3. • [<i>Homo habilis</i> is human], because the brain case size is big compared to the actual skull and if you actually put it next to a human its relative size will be almost the same. And the brow ridge is just a little more pronounced than a human, and its prognathism is like not very sloped. • They [hominin fossils] look like pretty close to what a human or a gorilla would look like. So I was surprised that they looked just normal. • I had <i>Australopithecus africanus</i>. And it took me forever to figure out how to say it. And it is more human-like and it basically has the same dental formula as the human.

Demonstrating understanding: Justifying claims.

Students engaged in another aspect of understanding, justification (Table 4.35). Smith and Siegel (2004) explained that students justify when they identify “considerations that render a claim *worthy of belief*” (p. 562). In simple terms, students engaged in justification when they explained why they thought the way they did, using evidence in their explanations. Students justified their claims a total of 64 times during the post focus group interviews compared to zero times during the pre focus group interviews. They justified: a) what they thought it means to be human, b) which hominin might be the “missing link”, and c) the hominid phylogeny they created on the table in response to my prompt: What are the relationships of the skulls on the table/How might you arrange them in terms of their relationships and in terms of time? Tables 4.35 and 4.36 organized student justifications.

First, the post interview prompt, What do you think it means to be human?, rendered conversation steeped with justification (Table 4.35). Most students justified what it means to be human based on physical characteristics alone:

A human [is] bipedal, has eyes in the front, is diurnal, an omnivore, has a large brain case, dental formula 2123 over 2123...no sagittal crest and reduced brow ridge. Like the Neanderthal would be like human, and the *boisei* would not be human.

Several students, however, argued that to be human, certain behavioral and/or cultural criteria must be met: Humans must “create and use tools, [have] civilization [and] organization, and... think about the future”. These findings align with the hominin skull learning experiences, which focused on skull characteristics, and shared, derived characters in developing phylogenies. However, the students noting behavioral and cultural aspects as criteria for being human are correct. Richard Potts and Christopher Sloan (2010) wrote a National Geographic book titled, “What does it mean to be human,” and they wrote an entire chapter on human innovation and imagination as unique human characteristics. Improvements to the hominin skull learning experiences might include a lesson regarding the behavioral and cultural components of being human.

Second, the post interview prompt, “Which skull do you think was the missing link” and “Why was Lucy such an important find?” also rendered conversation steeped with justification. Students justified their definition of “missing link”, justified whether the “missing link” was “Lucy” or *tchadensis*, and/or justified why Lucy was such an important find (Table 4.35). Conversations regarding the “missing link” can be traced back to the learning experience in

which students viewed the video “In Search of Human Origins, Part 1: The story of *Lucy*” (Gunton, 1994) and answered questions from the video as a part of the extinct skull learning experiences.

Table 4.35

Students Demonstrating Understanding of Hominid Evolution through Justification

Focused code (n=64)	Initial code	Marker(s)
Justifying...	what it means to be human	• I think it [being human] means that you're bipedal, you have forward facing eyes, you use tools, and you have a big brain. • A human [is] bipedal, has eyes in the front, is diurnal, an omnivore, has a large brain case, dental formula 2123 over 2123...no sagittal crest and reduced brow ridge. Like the Neanderthal would be like human, and the <i>boisei</i> would not be human. • To be human, you need to be <i>Homo</i>. Like <i>Homo sapiens</i>, you can be a biped. You have the dental formula 2123, very small sagittal crest...not a very sloped prognathism, smaller brow ridge. • But also like you know, somebody with a personality. You know that has some...variations of their brains so you know they act differently. So everybody can't be the same. • It [being human] was something along the lines as the ability of an organism to create and use tools, [have] civilization [and] organization, and to think about the future. • I agree with [fellow classmate], and but one more thing. They have to have a slight brow ridge, and a little sagittal crest. Like how the gorilla and the orangutan have a bigger sagittal crest. Humans are closest to the human skull. • I don't think it [<i>Homo ergaster</i>] looks very human visually. It's hard to tell with the brow ridge. But just if you infer, because it [brow ridge] is broken off, there would be a brow ridge that's slightly larger and humans don't have a larger brow ridge and the nose shape is not similar.
	Who/what is the “missing link”	• The missing link is the ancestor between human, chimpanzees, and gorillas that connects all of them. And it's probably from a long time ago. Because like others have branched off and become these three. And I think the missing link is <i>tchadensis</i>...it has characteristics from...like all three of them [humans, chimpanzees, and gorillas]. • We think that <i>tchadensis</i> is a common ancestor between gorillas and humans because it shares all the common characteristics of both of them. And it's older, so it's had time to evolve to both. It's got [the] 2123 dental formula like humans. It's got a pronounced brow ridge like the gorilla, a smaller brain case size like the gorilla. Eyes in the front like both of them. And then a foramen magnum on the bottom like the humans. • I think Lucy is the missing link...she's old enough I think to be the missing link and she also sort of has the characteristics of all three [humans, gorillas, and chimpanzees]. And it sort of made sense to the scientist [who] found her that she was like the missing link of all. And she couldn't show everything but she has a reduced brow ridge so it's not completely gone pretty much like the humans, but it's still sort of there like the chimps almost. And then it has it's sagittal crest, though. And it's prognathis[m] isn't as sloped [as the chimpanzee]. And then the dental formula is the same as the human. And so, I think it [Lucy] is the missing link.
	why Lucy was an important find...	• Well if I were a scientist on the dig and I found Lucy, I would be really excited because if you just look at her you can sort of tell that she looks like a human and sort of like a chimp. So she's not completely human but she's not completely chimp And like the fact that she's bipedal is like a big give away because...if they are bipedal that's like a big give away that they are human. • They [scientists] were probably real excited because they had no idea what the common ancestor could be. And then they cam across this [Lucy] which shared qualities with both the gorilla and humans. So they probably thought it [Lucy] was a good chance that that was the common ancestor since they had nothing else. • Well why it's [Lucy] is so important is when they found it, it just looked like [a] modern day human. But it's because they found it so far back is that they were like wow. When [did] this happen or whatever? But you know...they found the knee right? Yeah, they found the modern looking knee but the knee locked so you could walk bipedally. • Because it [Lucy] really wasn't what scientists thought it would be, because they said it...would have a lot of intelligence...and this one's bipedal. It [Lucy] really changed what they thought.

One student-participant (standing in Figure 4.5) gave a response worthy of particular attention. He gave impressive detail justifying why there may be many “missing links”.

Based on this [phylogeny on the table] we don't really have that many skulls with us right now. So, we sort of have a lot of missing links. Like there would probably be more and more and more [skulls], but we have limited skulls. If I look at it [phylogeny on the table] right now it kind of seems like, yea, Lucy is kind of like a missing link, but...if we never found *Homo erectus*, we would think that we along with *Homo neanderthalensis* and *Homo floresiensis* evolved from *ergaster*. And we don't really we can infer that that really didn't happen, and *ergaster* evolved into *erectus* and that evolved into Neanderthal, and *floresiensis*, and human. And there might be a missing link between *erectus* and these three (*Homo sapiens*, *Homo neanderthalensis*, *Homo floresiensis*) for all we know, but we might not have found it yet. I think that there are a lot of missing links, but Lucy was a really big find, and important to use because we wouldn't exactly know more about our history in this, because like the way that we set this [phylogeny on the table] up, if we didn't really have Lucy then we wouldn't know what's right here at all. Like we can see *tchadensis* back there and then be like *tchadensis* was alive for a long time and then it evolved into these two [*Homo ergaster* and *Homo erectus*]. But if you put Lucy down that kind of changes the story a little bit. Cause it kind of makes it so that you can see that there was something right there. And that Lucy did kind of branch off into a couple of different things, so.

This student-participant (standing in Figure 4.5), argued with rich vocabulary and description, why he thought there were many “missing links”. At the same time he showed his understanding

that the phylogeny his group constructed on the table was tentative, subject to change with the import of new fossil finds. Clearly, this student was developing the habits of mind of a paleoanthropologist.

I need to address the problematic nature of the phrase “missing link”, and the implications for pedagogy. Conversations regarding the “missing link” arose from the video featuring Don Johanson’s discovery of Lucy the shockwaves she sent through the paleoanthropological community. Don, the narrator of the video, referred to the notion of a “missing link” consistently. However, paleoanthropologists currently consider a “missing link” as “not a useful concept” (Potts & Sloan, 2010, p. 42). The terminology “missing link” begets a linear versus branched evolutionary picture, and implies that species can reach an identifiable point of stasis. In contrast, species are in constant evolutionary transition (Potts & Sloan, 2010). Future curricular modification might challenge students to investigate the “missing link” concept through a history of science lens, so that they can come to know the origins of the phrase, and understand why scientists currently use terminology such as common ancestor instead. Such an investigation would also be an example of how science changes.

Student-participants also justified phylogenies during the post focus group interviews. The following skulls were placed on the table in front of them: *Homo sapiens*, gorilla, chimpanzee, orangutan, *Homo neaderthalensis*, *Homo floresiensis*, *Homo erectus*, *Homo habilis*, *Homo ergaster*, *Australopithecus afarensis*, *Paranthropus boisei*, and *Sahelanthropus tchadensis*. Student participants were asked to work together to create a phylogeny. Student-participants collaborated together from between 2-4 minutes to create the phylogeny. I then asked student-participants to explain and justify their phylogeny, and change it if necessary as discussion ensued.



Figure 4.5. Student Justifying the Placement of Hominin Skulls within a Phylogeny.

I present the data from two focus group interviews. The data showed that students: a) engaged in situated learning, b) gave priority to evidence when justifying their phylogenies, and c) used comparative anatomy, the variable of time, and knowledge of contemporary species to justify evolutionary relationships.

The first focus group (focus group A) I discuss, initially arranged their extinct skulls one behind the other, depicting evolution as a linear process (Figure 4.6). One student explained:

I would put these five skulls in this line [student placed the following skulls in a line on the table during the interview: *Homo sapiens*, *Homo neanderthalensis*, *Homo ergaster*, *Australopithecus afarensis*, *Sahelanthropus tchadensis*], because they are all somehow related to the human skull. Because it looks like for millions of years...they evolved into a human skull. [I put the gorilla by the human] because its currently living at the same time as the human. So, it can't be behind...the human. [I placed the skulls in this order] from littlest [*tchadensis*] to biggest [*Homo sapiens*].

This student justified the phylogeny, using time and comparative anatomy (skull size) as supporting evidence.

Focus group A – 1st Phylogeny



Focus Group A – Amended Phylogeny



Figure 4.6. Focus Group A Justifying and Amending their Hominid Phylogeny.

I asked if anyone want to change the phylogeny (Figure 4.6). Another student applied knowledge of contemporary species and comparative anatomy (skulls as more human versus gorilla-like) to justify a modified phylogeny:

I would change it [our phylogeny] a little bit [student refers to the phylogeny of skulls on the table]. I would put this kind [student picks up *Homo neanderthalensis*] like that [student places *neaderthalensis* laterally to *Homo sapiens*, but slightly behind in terms of time] because they were contemporaries at one point. And then, [this] right here [student picks up *Homo ergaster* and places it behind *Homo neaderthalensis* in terms of time] and then this one kind of in the middle [student places *Australopithecus afarensis* behind *Homo ergaster* in terms of time, but in the middle of human and gorilla]. And that one kind of in the middle [student places *Sahelanthropus tchadensis* behind *Australopithecus afarensis* as far as time, but in between human and gorilla], because these two [*afarensis* and *tchadensis*] behind they have similarities of...the human and gorilla.

This student moved skulls in such a way to create a bushier phylogeny. She added evidence (knowledge of contemporary species and comparative anatomy regarding human-like versus gorilla-like skull characters) to justify the changes she made.

The second focus group I discuss (focus group B), demonstrated similar cognitive processing. Students worked together to create the phylogeny, and justified their phylogeny using comparative anatomy, the variable of time, and knowledge of contemporary species. Amendments to the first phylogeny were made based on subsequent group discussion, but only after I queried the students further. I discuss the important role of the teacher in stretching students' cognition.

Student participant A (standing in Figure 4.7) explained the initial phylogeny. He stated that the skulls were in chronological order and identified the skulls with scientific names. He also made claims about evolutionary relationships, yet did not provide justification. However, a good introduction for subsequent conversation was made.

Well, they are in chronological order. The humans are very still alive and then you have the *Homo neanderthalensis* and the *Home floresiensis*...I think these guys [participant points to *Homo sapiens*, *neanderthalensis*, and, *floresiensis*) are all from *habilis*. I think *Homo erectus* did [evolved from *habilis*] too. But I think that...*boisei* ...there's not strong evidence, but he might have been evolving into the chimpanzee and the gorilla. And then I think he [*boisei*] and *habilis* evolved from...[other student participants provided input]...*ergaster*, that's it...and then Lucy and *tchadensis*.



Figure 4.7. Focus Group B Justifying and Amending their Hominid Phylogeny

Student participant B (obscured by student participant A) followed up, saying:

We think that *tchadensis* is the common ancestor between gorillas and humans...because it shares all the common characteristics of both of them...it's got the 2123 dental formula like both of them. It's got a pronounced brow ridge like the gorilla, a smaller brain case size like the gorilla, eyes in front like both of them, and then a foramen magnum on the bottom like the humans.

Student-participant B made a claim about the common ancestor between humans and gorillas, giving ample amounts of evidence to support his claim. He drew on his knowledge of comparative anatomy to justify his claim. Interestingly, he stated that “We think”, perhaps indicating a mindset of scientific collaboration, an aspect of learning situated in paleoanthropology.

Student participant C (the lady of the group) agreed with the initial phylogeny as well, but added insights in line with both the sense-making and justification criteria for understanding (Smith & Siegel, 2004).

I think they covered most of it. But, just how where they are placed shows the common ancestor and how they evolved. I think *tchadensis* is the common ancestor between *Homo*

sapiens and humans because it's the oldest and it has a lot of qualities and characteristics of the gorilla and human. And it does have time to evolve.

The unique contributions of participant C were made evident when she noted that the visual phylogeny “show[ed]...how they evolved”—perhaps indicative of acceptance of human evolution, with acceptance as analogous to “Rhetorically Compelling” in Dole & Sinatra’s (1998, p. 119) CRK model of conceptual change. Also, participant C further justified the designation of *Sahelanthropus* as the common ancestor of humans and gorillas, because of its age. This comment may show understanding of macroevolutionary time (Catley, 2006). Student-participant D (opposite student participant A) also agreed with the initial phylogeny, but wanted to add more explanation and justification. He gave more evidence to support *tchadensis* (using comparative anatomy) as the common ancestor of *Homo sapiens* and chimps/gorilla. He also provided more evidence to support the evolutionary placement of *erectus* and *habilis*.

I agree with them. There is one thing I want to add...it's [*tchadensis*]..skull size is close to the chimps. That's [skull size is] what links the chimps. And it's [*tchadensis*] got...the brow ridge which both of them [chimp and gorilla] have. And that sagittal crest is pronounced about the same as the chimp....[*Homo erectus* is placed laterally between *Homo sapiens* and gorilla] because it is not exactly like a human... and it's kind of towards the *Homo neanderthalensis*, because it's got a big brain case size like the Neanderthals have. That one [*Homo habilis*] looks similar to that one [*Homo floresiensis*]. So I think we thought these [*Homo habilis* and *Homo erectus* were] about the same time....

I was pleased with the responses of all participants, as they gave priority to evidence when justifying the phylogeny. I was also pleased to see that they worked together to create the phylogeny, and offered their own unique views to build on the comments of their peers.

However, I pressed the focus group participants to think more about their phylogeny. *Neanderthalensis* and *floresiensis* were placed behind *Homo sapiens* rather than laterally as contemporaries. Students had also placed *ergaster* and *boisei* in the chimpanzee/gorilla lines, in spite of their bipedal status. I asked student participants “What does our picture show as far as what is the most recent ancestor to humans” as illustrated by your phylogeny? Participant C replied, “Neanderthal”. I followed, “So you would say *neanderthalensis* evolved into humans? Participant D responded:

well the human existed around the same time as Neanderthal...so it [Neanderthal] couldn't evolve from them [*Homo sapiens*]. It would have evolved from like *Homo erectus* or something like that.

Students A and D proceeded to move *neanderthalensis* and *floresiensis* into their rightful positions, laterally to *Homo sapiens*, and slightly behind as they have gone extinct.

Unfortunately, we moved on to conversations about Lucy instead of reconsidering the positions of *erectus* and *boisei* given their bipedal status. I think with a little prodding, student-participants would have modified the phylogeny even further. I think that my presence during this conversation was important to help students further unpack and construct their own student knowledge and/or understanding.

The post focus group interview conversations regarding the hominid phylogeny constructed on the spot, suggested the need for some curricular modifications. Students needed help in understanding why all of the skull specimens were classified as hominins. A lesson

dealing with molecular clock data might help with the construction of this understanding.

Another lesson might encourage students to investigate which hominin characteristics are both shared (common to all hominins) and derived (different from gorillas and chimpanzees).

Students might discover the defining characteristics of the hominins (i.e., the position of the foramen magnum and reduced canines) that relegate them to the human clade versus the gorilla or chimpanzee clade. One student-participant, hit on shared/derived characteristics in her justification of the focus group phylogeny, so I know students would be capable of grappling with this concept:

I think it [hominid phylogeny] kind of shows like how one species might come from another. Because if you look at the gorilla and then look at the human, you'll like see that it's really, really different. But then if you slowly go through all the other skulls...if you like take the cheekbones for instance. The cheekbones are really wide. And then it slowly, like that one has wider cheekbones and it [cheekbones] slowly becomes smaller and smaller until it gets to human. And it's the same with other features. And so you can kind of see where it kind of trails together and how features evolve, and you can see it changing. Like in chronological order. And so it kind of shows how species can branch off from each other.

Last, participant A of focus group B suggested the need to address anthropomorphic attributions to the skulls. He sometimes referenced a skull as “he” rather than by genus name. This student may have also been having difficulties with visualizing human evolution in terms of species, and may have harbored the alternative conception that evolution occurs on a more individual level. This alternative conception may have been reinforced by the limitation of using single skulls to represent entire species. These issues might be addressed in teaching through explicit

conversation regarding the process by which fossils are named scientifically and identified numerically to avoid anthropomorphism. A learning experience dealing with natural selection, but using the human example, might address evolution at the species rather than individual level. Technological innovation might have a critical place in developing simulations of speciation and natural selection.

Demonstrating understanding: Applying knowledge.

Thus far in this understanding section, I have shared data codified under “making connections” and “justification”, leaving “application” and “sense-making” for discussion now (Smith & Siegel, 2004, p. 562). Students engaged in application fourteen times during the post focus group interviews compared to zero times during the pre focus group interviews (Table 4.36). Smith and Siegel (2004) explained, “A person can be said to understand a concept if he/she can apply that understanding appropriately in both academic and non-academic settings” (p. 562). Student-participants applied their understanding of evolution to the future of human evolution. I asked student-participants, “If you could fast forward a couple of hundred thousands of years, how might humans be different than they are today?” It was interesting that most student-participants reasoned that *Homo sapiens* would not evolve in the future because of our intelligence and ability to socially adapt. And of these student-participants, one mentioned that gorillas may have to adapt because of their endangered status, suggesting teleological thinking. Only one participant suggested that *Homo sapiens* would evolve, but she added, “you can’t really tell...because it’s completely unpredictable”. I am not sure if this student was referencing to the unpredictable nature of mutation, or environmental change, or both. This data may support other findings that learners have difficulties seeing our own species evolve versus other species (Sinatra, Southerland, McConaughy, & Demastes, 2003).

Also important to mention, students appeared to enjoy talking about human evolution in the future. One focus group in particular, stayed on the topic more than twenty minutes, and even resisted my prompts to move on to other interview topics. New learning experiences might tap into this motivation to learn. First, visualizing the future of human evolution might help students apply understanding of natural selection in a new and creative way. However, scenario and resource building would be necessary on the part of the teacher, to better set the stage for the construction of knowledge. Climate change data could be used to depict a futuristic global scene. Conversations regarding natural selection, competition, and mutation could then ensue.

I have also considered how to embed more application activities within learning experiences. The activity idea that follows, is unrelated to the future of human evolution, but requires student to apply understanding in a different way. Near the end of the hominin skull learning experiences, I could present student-participants with a new hominin fossil find. Their task would be to recreate the life history of the specimen and place the specimen in a previously created phylogeny. Students could be assessed based the extent to which they give priority to evidence and justify claims, and the NOS as tentative could be explicitly reviewed.

The data in this application section further challenged my thinking about what it means to understand. Students were applying their knowledge in a new context, fitting Smith & Siegel's (2004) definition of application and therefore understanding. However, errors in knowledge were embedded in student responses, such as teleological thinking. Perhaps educators should envision a continuum of understanding, ranging from understanding with minimal references to sound knowledge to optimal understanding with the demonstration of sound knowledge.

Table 4.36 <i>Students Demonstrating Understanding of Hominid Evolution through Application</i>			
	Pre n=0	Post n=14	Markers
Application	0	14	• Possibly, we could. I think maybe humans will still be alive in the future. But I also think that maybe humans, chimps or gorillas will eventually evolve into something. But I'm not...you can't really tell. You can't just say that this is going to happen. That's going to happen because it's completely unpredictable. • I think humans will stay the same cause we keep advancing our technologies which we've overcome many things like sickness. We can defeat most sickness now that's why where our population is just growing and growing. Cause that was actual one of the natural selection that probably got rid of a species is they caught a disease that destroyed the species. And we're learning how to defend against famine. And we're growing everything ...so we're making enough food for everybody and we're not worrying...that we'll run out of food or soil because we're figuring out new ways to make everything. But like the gorillas, they're getting close to extinction, and so I believe a few of them might ... • I don't think that we're ever going to see the type of evolution we've seen before. Because our brains are bigger, we won't have to adapt our bodies physically, because we have the technology. We will just socially adapt and have technology adapt for us. • I don't think we'll ever in a 100,000 years go extinct because of the technology. Like before we had the predator-prey relationship. You could see that nature would just make the population go up and down and it would never increase like the human population is today. And that's [increase in human population] because of all the technology...and that [technology] would make us survive even longer and not change. • Looking at how we evolved and we can...find out why the other species went extinct. So maybe, when we grow up if we want to be scientists, we'll figure out ways that we can stop us from...becoming extinct. By looking at these characteristics and seeing why they did [went extinct], so that we would prevent us from becoming extinct.

Demonstrating understanding: Engaging in sense-making.

Last, students engaged in sense-making during the post focus group interviews. Smith and Siegel (2004, p. 562) used Gauld's (2001) definition of sense-making, "Understanding is... 'making sense' of something of attributing meaning to it". Student-participants engaged in sense-making a total of 42 times compared to six times during the pre focus group data (Table 4.37). Many of the sense-making codes were made during conversations regarding human evolution and bipedalism. Students reasoned that the selection of bipedalism occurred to free the hands, for the use of tools, for hunting, and energy efficiency (Table 4.37).

No curricular experience directly addressed questions regarding the selection of bipedalism. A curricular modification might include a learning experience that a) has students complete daily tasks but without the use of their hands so that they can understand the

significance of freeing the hands, and b) apply natural selection to explain how the selection of bipedalism might have occurred.

Sense-making also occurred during the post focus group interviews when I asked students to look at and tell me about a hominid phylogeny presented in the book *The Complete World of Human Evolution* by Stringer and Andrews (2005, p. 12). Student-participants had previously examined this same phylogeny as a summarizing activity during the Hominid Hallway Timeline learning experience. So this phylogeny was not totally foreign to students. During the post focus group interview, student-participants made sense of several concepts: a) contemporary hominin species, b) the separation of the human, chimpanzee, and gorilla clades, c) the common ancestor of gorillas and chimpanzees, d) hominin diversity, e) macroevolution, and f) ancestors of *Homo sapiens* preceding *Sahelanthropus tchadensis*.

I think this data supports the benefits of having student make sense of a phylogeny presented by the experts. But, I could expand this experience and have students compared their own phylogenies to the one created by the experts. They could make two or three amendments to their own phylogenies given this new data source. This activity might help students engage in one of the essential features of inquiry not tapped into thus far in my study. This essential feature, “Learner connects explanations to scientific knowledge” is optimally actualized when a “Learner independently examines other resources and forms the links to explanations” (NRC, 2000, p. 29). In this example, my student-participants could independently examine Stringer and Andrew’s (2005) hominid phylogeny, and link knowledge gained to their student-generated phylogeny.

Table 4.37 <i>Students Demonstrating Understanding of Hominid Evolution through Sense-making</i>			
Initial code	Pre n=	Post n=	Marker(s)
Sense-making	6	41	• It was really interesting to see how you could see us the homo sapiens. But if you look at all the other bars for how long they lived, you can see that <i>neanderthalensis</i>, <i>floresiensis</i>, and <i>erectus</i> were all alive at the same time. And we're really evolved just from humans. Because even the earliest one you can see that it was still a human...Homo ergaster had gone back...well, it looks like maybe about two million years...just the homo genus has been here. And, before that there were still other species of humans. It may not have been the same genus but, there are still different types of the general human. So, we've been around for a really, really long time. And we couldn't have just evolved from a modern day gorilla. Definitely not. Because even gorillas, you can see that they, and <i>Pan</i>, they both evolved from <i>catalaunicus</i>...and that does not even relate over to the humans. If humans came from anything, it would have been a Kenyapithecus or Proconsul probably. • Because bipedal you can use your hands. Instead of walking on them you can use tools. Tools have helped civilizations grow. Like the spear, it helped the humans hunt for food. So they didn't have to fight for it. They could just attack with the spear, and use the tool instead of having to use their feet and hands. • I agree with the hands, but I also heard about an article that by walking upright bipedally is more energy efficient.

Cognitive outcomes: Views of NOS post intervention.

Table 4.38 organizes the NOS views student-participants expressed post-intervention.

The pre focus group data did not render a NOS table, so a pre to post comparison was not possible. I think the intervention was responsible for developing most of the NOS views in Table 4.38, because students often explained themselves using the context of the hominin skull learning experiences. Impressively, this data supports the notion that students may have been grasping NOS concepts (i.e. scientific knowledge as tentative and science as a creative and imaginative process) not usually taught by teachers Southerland and Nadelson (2012) found that teachers were most comfortable teaching a) the difference between theories and laws, b) science as empirically based, and c) science as bound by certain epistemological assumptions—in spite of staff development encouraging a broader sense of the NOS. An original contribution of this study attests to the potential of a human evolution curriculum to encourage the learning and understanding of more abstract NOS concepts. Also, student-participants grasped NOS concepts (i.e., science as multidisciplinary and divergent thinking) not listed in Lederman's (2007) top

seven NOS concepts. This also supports the notion that this human evolution curriculum demonstrates a diverse array of NOS concepts.

One student-participant was particularly eloquent in expounding on the ability of science to answer all questions:

I think that all questions are going to be asked in science. I don't think all questions can be answered with science. Like the question, what's going to happen after we die? That cannot be answered by science, at this day and age...maybe some time in the future...there's going to be new technology that allows us to study souls. I mean, maybe there's...a source of energy that could be studied with some new invention by someone in the future...and I think more and more questions will be answered as time goes on. But that will open up other questions. So it will just be a continuous process. You cannot possibly answer all questions. For example, and...this is just a random thing I'm just coming up with. But say you could study the afterlife. Say you could look at somebody's soul and see what happened as they went in...that would be the same as looking in there, as getting in a telescope and looking out past whatever we've seen as far as we could now...so it starts out with one question. What is the after life? You go in there. Now you say, what is this aspect? What is this, this, this, this and this? Which opens up those [questions]. You solve one of those [questions], that opens up more...continuous, continuous questions, continuous unanswered questions...

I think this excerpt attests to the ability of hominin skull learning experiences to engender rich discussion and critical thinking regarding the theoretical place of science. More impressively, a 7th grader, an early learner of science, shared this type of conversation. Therefore, 7th graders are

capable of joining in the conversation regarding the NOS. So teaching and learning efforts regarding science theory should and can occur during middle school.

Table 4.38

NOS Concepts Expressed during Post Focus Group Interviews

Focused Code	Initial Code	Maker(s)
Science as...	multi-disciplinary	- I thought that science was boring itself. Because I thought that the only really important type of science that we learn in school is with scientists with lab coats. The one's that do experiments, test tubes, all that stuff. And once we sort of started moving into this more life science and stuff like that, and learning more about creatures and living organisms from the past and present. I thought it was interesting because I didn't know that there were certain professions that didn't involve that type of aspect. It was more of digging and finding and piecing together...it gave me more of a general idea of what science was, because I just had one basic theory of what it was at first. But now I've sort of opened my mind a little bit more. - I never knew there were so many different kinds of science.
	tentative	...we don't really have that many skulls with us right now so we sort of have a lot of missing links. Like there would probably be more and more and more. But we have limited skulls kind of right now, so if I look at it right now it kind of seems like yea, Lucy is kind of like a missing link. But like <i>Homo erectus</i> if we had never found <i>Homo erectus</i> we would think that we along with homo....and homo..... evolved from ergaster. And we don't really we can infer that that really didn't happen. And the ergaster evolved into erectus and that evolved into Neanderthal andhuman. And there might be a missing link between erectus and these three for all we know. But we might not have found it yet. I think that there are a lot of missing link but Lucy was a really big find and important to use because we wouldn't exactly know more about our history in this. Because like the way that we set this up if we didn't really have Lucy then we wouldn't know what's right here at all. Like we can see....back there and then be like..... was alive for a long time and then it evolved into these two. But if you put Lucy down that kind of changes the story a little bit. Cause it kind of makes it so that you can see that there was something right there. And that Lucy did kind of branch off into a couple of different things. - If we look at this tree [student participant referring to skull phylogeny on the table], we could think that orangutans,...chimps and gorillas evolved straight from <i>boisei</i>, and we might even think that now. But if we find something else in between, that will completely change it [the phylogeny]. - Yes [science can change]. Because if we found like new evidence or clues or something, it could change the whole theory of what you think.
	Creative	- I absolutely love to think outside of the box, and still have that curious mindset about things. So, I love to think about how this [hominin] could have gone extinct, making more inferences about all the characteristics of the skulls, and thinking about the future. You could just go beyond and beyond and just keep going about all of your ideas about the topic and I just really enjoyed learning about it. - I go along with what [fellow classmate] said. I think that did surprise me [the brain case size of <i>Homo neaderthalensis</i>] a lot cause it does kind of change it up. You have to make different inferences and think beyond and be more creative cause we've been thinking that your brain case size decides how smart you are.
	divergent	[After the simulated fossil dig, I had] more unanswered questions. ...there are so many gaps in the fossil record. Like we learned to the best of our ability and we learned to the best of the science ability, but because there are so many gaps, it leaves you with so many questions. It's a little confusing...you just look at it and you're like wait, how come does that lead to that just cause you are left with so many questions. Like I gained like tons of knowledge but I also gained tons of questions. - but also I wish there were definite answers instead of just inferring and inferring because we can't know for sure and that kind of is like you can't totally base everything on it. You just infer....but there is still that little doubt in your mind. Well, they just say infer. They don't say they know for sure. You really kind of want to trust them, but a little part of your mind is like wait a second.

Other NOS gains were made, but in the context of paleoanthropology. Student-participants expressed an increased understanding of how the discipline of paleoanthropology works. Student participants explained that what we know about human evolution involves piecing evidence together, tedious work, or making inferences from partial evidence:

- I think it [human evolution unit] added to it because you can kind of see like how archeologists work...which are scientists too. And like how they put things together and how we puzzle things together and like we have a question...and it's how we learn about things...and how we put things together and learn more about like evolution and different things we wonder about.
- I think it's interesting how many different little pieces some these [fossils] come in, and how much digging [and] searching some people have to do [to] just find pieces. And, they may not even get the whole skull.
- Some of the parts [of the skulls] are just inferences. They're added on, or were made to complete the skull.

Another student-participant recognized that the current and active nature of paleoanthropology. He/she stated that, “scientists are still trying to work with finding fossils”. Specifically discussing paleoanthropology during the post focus group interviews may have indicated that students were engaged in situated learning, learning couched in the discipline of paleoanthropology.

Students also improved their knowledge and understanding of science as empirically based, and in the context of evolution (Tables 4.39 & 4.40). Data from the extinct skulls anticipation guide (Figure 3.11) completed pre and post intervention, provided some insights regarding the development of this NOS concept. The first prompt of this anticipation guide asked

students to comment on the statement, “What scientists know about evolution is based on observation”. Pre intervention, five students were either not sure ($n=1$) or convinced that evolution could not be based on observation because it occurred in the past ($n=2$), and that only inferences could be made regarding evolutionary claims ($n=2$). Moreover, six students stated that evolution was based mainly on observation, but did not go into more detail. All but one of these student-participants ($n=10$) showed cognitive movement post intervention.

Table 4.39
Student Responses to “What Scientists Know about Evolution is Based on Observation”

Focused Code	Initial Code		pre	post	
What scientists know about evolution is...	Don't know		1	0	I don't really know much about fossils. I would say it is sort of false [i.e. the statement 'evolution is based on observation'] because they have to guess or have an educated guess on what animals look like before us.
	Not empirically based		2	0	What we know about evolution can be based on observation like the peppered moths. However, things like humans evolving from gorillas cannot be based on observation, because we cannot look back before our time.
		inference	2	0	Scientists can't observe evolution because it takes long to happen, and so we have to infer why animals or living things are different.
	Empirically based	Mostly observation	6	1	What scientists know [about evolution] is based mostly on observation.
		Observation	9	11	- Scientists can observe change in fossils over time. Looking at bones in chronological order. You can observe changes. Looking at DNA, if there is any, can be considered observation. - What scientists know about evolution is based on observation. All facts in science are based on collected data. The data is collected by observation, making is so all scientists know about evolution based on observation. - Scientists know about evolution because they have observed fossils millions of years ago. Scientists observe the characteristics such as dental formula, prognathism, position of the foramen magnum, and brow ridge to classify a species. - Scientists observe fossil most of the time, but they also do carbon dating and argon dating too. - Scientists observe fossils to determine evolutionary theories.
		Observation and inference	6	12	- Scientists can observe some evidence, but by piecing together fossils and creating a 'tree', but sometimes they have to infer about evolutionary history, such as finding the missing link, or how old an organism may be. Most of what scientists have collected about evolution has been through observation, but the rest is by inference. - Scientists have found out that evolution is true by finding fossil. Scientists found the fossils by observing, but figured out evolution by inferring. [So] evolution is based on observation and inference. - What scientists know about evolution is based on both observation and inference. The skull we observe, we made a lot of inferences on what it looked like and how it lived.
		tentative	1	2	- Scientists do observe skulls and fossils, but they infer things about the skull. Such as if they foremen magnum is directly under the skull, they infer it walks bipedal[ly]. And scientists infer if two organisms are similar in many ways that they have a common ancestry, but it might not be true. What scientists know about evolution is based on observations as well as inferences. - For a scientist to know something is 100% fact, they must have observed it. Other information is based on inferences, but scientists don't know it's true for sure. Most of what scientists know about evolution is based on observation.
		retrodictive	1	2	- Scientists know about evolution from fossils. They did not actually see it happen, though. They made an inference based on the fossil, [so], what scientists know about evolution is based on inference. - Evolution is based on observation, but some scientists infer about evolution, because they were not there to see it happen. [So], scientists know about evolution by observations and inferences.

All student participants (n=28) (Table 4.40) agreed that what scientists know about evolution is based on observation by post intervention. The number of students who realized that

evolution is based on observation and inference, and that our knowledge of evolution is both tentative and retrodictive also increased. Table 4.40 gives several examples of how student participants improved their thinking in regards to the empirical nature of evolution.

Table 4.40 <i>Tracking Student-participant Change: The Empirical Nature of Evolution</i>		
Student	Pre student response	Post student response
	Pre initial code	Post initial code
I	What we know about evolution can be based on observation like the peppered moths. However, things like humans evolving from gorillas cannot be based on observation, because we can't look back before our time.	...some evolution is based on observation, but some scientists infer about evolution, because they were not there to see it happen....scientists know about evolution through observations and inferences.
	Not sure	Empirically based, retrodictive
J	I don't really know much about fossils, but if I had to guess, I would say it is sort of false [the statement that evolution is based on observation]. I say that because they [scientists] have to guess or have an educated guess on what animals look like before us.	What scientists know about evolution is based on both observation and inference. The skulls we observe, we may make a lot of inferences on what it looked like, and how it lived. What scientists think about evolution is based on observation and inferences.
	Not empirically based	Empirically based, observation and inference

I was generally pleased with post anticipation guide responses to “What scientists know about evolution is based on observation”. However, I should have also had students address this statement during the post focus group interviews as a way to further validate the data in Tables 4.39 and 4.40, and to further unpack student views. Student participants codified in the empirically based, observation initial code, may in actuality, hold less absolutist views when queried further. I did not guide students in this conversation post interview, due to my own shortcomings as a teacher researcher, and due to my eagerness to discuss other topics on the interview protocol.

In sum, the NOS data generated from the post focus group interviews, and supplemented by the extinct skulls pre/post anticipation guide, suggested that student-participants improved

their notions of NOS because of the curriculum intervention. They broadened their views of NOS (e.g., adding views that science is a creative, imaginative process), and expressed the empirical nature of evolution.

Cognitive outcomes: Explaining how evolution happens.

Two post focus group interview prompts challenged students to think about how humans might evolve in the future:

- If you could fast forward a couple of hundred thousands of years, how might humans be different than they are today?, and
- How might this human evolutionary change occur?

I compared how students explained how evolution might happen with the example of humans, with how they explained evolution during the pre focus interviews using other examples (e.g., peppered moth, giraffe, komodo dragon). Table 4.41 shows this data. The post focus group interview data suggested that students had more difficulty applying the concepts of natural selection to human evolution compared to other animals. Teleological thinking remained relatively the same (39% pre intervention compared to 36% post intervention). Surprisingly, normative thinking alone decreased from 57 to 48%. Student-participants became more likely to blend teleological and normative thinking when explaining human evolution. This phenomenon may have occurred because learners often have a more difficult time conceptualizing the evolution of humans compared to other species (Sinatra, Southerland, McConaughy, & Demastes, 2003). Also, there was no learning experience that required students to apply the concept of natural selection to human evolution, suggesting the need for curricular modification in this area. Collaboration with a paleoanthropologist and/or computer programmer might be needed to create such a learning experience, such as a board game or computer simulation.

Table 4.41

Hominin skull learning experiences: Explaining Evolution

Focused code	Initial code	Pre n=28	Post n=25	Marker(s)
Explaining evolution	Demonstrating teleological thinking	39%	36%	- I agree with [John] Without their hands, they couldn't hunt with like a tool like a spear. And they just needed hands to adapt and survive. - I think we'd be about the same. We might have a few variations because there's always something that could be improved. Always something you can make better. But for the most part I think <i>Homo sapiens</i> have been pretty successful so I think they will live on for a long time.
	Demonstrating normative thinking	57%	48%	- I don't think we'll ever in a 100,000 years go extinct because of the technology. Like before we had the predator-prey relationship. You could see that nature would just make the population go up and down and it would never increase like the human population is today. And that's [increase in human population] because of all the technology...and that [technology] would make us survive even longer and not change. - Maybe we will go extinct because of all of the development going on. Maybe they'll cut down all of the trees possible, and then there won't be enough oxygen. We will just die off...And maybe there will be too much over-development that there will be no other place for people to live and they won't have any food and we'll die of starvation. - one more thing. With all the new science and genetic mutation is suppose to be almost perfect by 2012 they say where you can change eye color of your baby. Tell how tall they are going to be. That should almost be perfection 2012 so I think if someone it might be harder for us to go extinct because we can go into the DNA of our offspring pretty soon and be able to change them so they will adapt and they will live on.
	Demonstrating teleological and normative thinking	4%	24%	- I think humans will probably [and] relatively look the same. But we might have a couple of different adaptations cause we'll probably need a different way to breathe. Cause pretty soon the oxygen's going to go out because of global warming and deforestation. And I think gorillas and chimpanzees either they have to adapt and evolve or they're going to go extinct. - A lot of the examples we talked about were caused by a drought which affected the food supply. But, with the early humans it might have been that they were just moving from place to place and there were different conditions everywhere that they went and they had to adapt.

Cognitive outcomes: Negotiating science and religion.

Conversations regarding religion were not directly broached during the post focus group interviews, unless there was a natural segue to do so, or unless a student initiated this conversational direction. I did not intend to bring up the topic of science versus religion in the post focus group interviews. The topic was not a part of our learning experiences, and I was committed to the separation of church and state. I also respected my students and their families, and felt that the home was the best place for students to discuss the science/religion issue.

However, several students contributed insights regarding how they negotiated what they were learning in our science class, versus their religious teaching. They gave these insights after I ask them if 7th graders should learn about human evolution. Two students expressed that God may be responsible for the evolutionary patterns we were discussing in the class. For example:

They [seventh graders] should learn about it [human evolution] but they should learn about it so they can get a whole rounded picture, because if they are religious, religious people believe God created it, which I believe is my theory in life, that god created everything...now learning evolution, I believe god created evolution. He wanted that to happen. So he didn't just create humans automatically because we don't know how long his days are or anything like that. So his days may be billions of years long.

The excerpt above suggests that students may have negotiated the science/religion issue in a positive way and perceived that “science and like religion don't really conflict that much. You can find an explanation that allows them to like fit together”. Students reasoned for compatibility. Another student articulated his “belief” in both evolution and God, giving an impressive rationale for his own definition of belief:

Science is basically, like, if you just take away everything, it's observation. I mean, science is not like any other thing in the sense that you cannot think of something and have it be science. Like I mean, math is in a sense science because once you discover one plus one equals two, it is that...[and] that's an observation. And thus, it becomes a fact, which means it's science...like by the statement that I've heard places, it's, science is a system of beliefs. Um, I believe that it's true. Because a belief to me is something that there is evidence of it. Whether it be physical or otherwise. And it means that you feel strongly about it and you think and completely just know that, that is to be true. I

mean...that is something that you feel so strongly about and you've like thought it over. And I don't know, maybe people have talked to you about it. But whatever the case, you believe in it. I mean, it is there for you. Whether it be true complete observation such as, I don't know, evolution. Or as to the belief in God and like the Christian sense as it is for me. I believe in evolution just as much as I believe in God. Well, maybe not as much. But evolution to the point is, I have to believe it. Because there is facts. I mean, unless someone shows me, like comes up with another skull that says, oh look, that this is different, that's not right. Then I will obviously not believe in it. But to a point where God is, in like the Christian sense again. Somebody would have to do the same thing in order for me to not believe in it.

The response of the student-participant above suggested that the hominin skull learning experiences were “comprehensible”, “coherent”, “plausible” and “rhetorically compelling” (Dole & Sinatra, 1998, p. 120) enough for this student-participant to believe in evolution, and therefore required this student-participant to integrate evolutionary theory with his preexisting conceptual framework.

Only one student-participant suggested that the hominin skull learning experiences had their “negatives”. This student explained:

I think it [hominin skull learning experiences] has it's pros and it's cons. It's positives and negatives. Because depending on your religious beliefs or theories about the earth and how it was created. It's sort of ...make[s] you halt where you are and just sort of think about it. Because if you believe that we are created by God or that we've only been around for a certain amount of years. And then you do all this stuff [learning experiences with hominid skulls] and you know that it's most likely true. It sort of makes you doubt

yourself and think, well, am I thinking the right thing or am I just, just thinking something wrong. So, it is good. But at the same time, it's sort of bad because it just sort of makes you doubt yourself. And, but it is good to double think stuff and sort of review what you've learned in the past. So, it has its positives and negatives.

This student-participant doubted himself and his religious upbringing because of the hominin skull learning experiences. He considered this doubt to be a “negative”, because he had to reconsider his religious teachings, such as the age of the Earth. However, he also viewed doubt in a positive sense, because it challenged him to critically think about what he had been taught previously. I am sure this student-participant’s views represented other student-participants in the class, given the conservative Christian climate of our community. In one way, I question myself as a science educator. I don’t want to cause that initial crack in someone’s worldview, which could come tumbling down and be very difficult to reassemble. On the other hand, I have an ethical commitment to represent science—to be that conduit between the scientific community and the learner. And, if the purpose of an education is to broaden one’s thinking (as Dewey would argue (1938)), then the topic of human evolution unequivocally does so, and should be a part of science education. Also important to consider, no student-participants responded in an overtly upset or deviant way during the hominin skull learning experiences. In contrast, students appeared engaged and enthusiastic to learn. So overall, the positive affective and cognitive outcomes that were detected through data analysis, outweighed the one negative expressed by the student-participant above.

Thumbs up, thumbs down, or thumbs in the middle?: Should 7th graders learn about human evolution?

Final post interview prompts had students either rate the hominin skull learning experiences with a thumbs up, thumbs down, or thumbs in the middle, or argue for or against teaching the topic of human evolution in 7th grade. Students overwhelmingly responded with a rating of “thumbs up”, or encouraged the teaching of human evolution for various reasons. Table 4.42 organizes why students supported the teaching and learning of human evolution for various reasons, because a) “this was extremely fun”, b) “seventh grade is when you start to think about religion and stuff”, c) “it teaches you where you came from”, and d) for “deciding what career want to work on”, and for paleoanthropology, which “could one day answer where we really came from, or where we really evolved, or what’s the missing link”.

Table 4.42 <i>Thumbs Up, Thumbs Down, or Thumbs in the Middle, and Should 7th Graders Learn about Human Evolution?</i>		
Human evolution should be taught...	because its so fun.	I think thumbs up because we need to this was extremely fun because we got to work with skulls and I think we were the only class in the whole school that got to do this. And it was a really fun experience.
	Its time in 7 th grade to start thinking religion and human origins.	Yeah [they should learn about evolution] cause seventh grade is when you start to think about like religion and stuff at that age. And you start to wonder how and why you became human and this is a pretty good explanation. And it’s useful for you.
	we learned more about our evolution or human origins.	- I would say thumbs up, because it teaches you where you most likely came from and how humans evolved and [how] gorilla and chimpanzees, how we’re all related. And, how different we may look, but how similar we are [when] looking closer. [This unit was a thumbs up] because we were taught about where we came from. - Thumbs up because we really got to learn what paleontologists do. And,discover fossils to study them and to learn...more about evolution. - I think they should [learn about evolution] just because it was you know very informative and very helpful and I got a better understanding of evolution.
	for the future of paleoanthro- pology our future jobs.	- Yes [human evolution should be taught] because they [paleoanthropologists] could one day answer where we really came from. Or ,where we really evolved, or what’s the missing link. It [paleoanthropology] could answer one of those questions - We should [learn about human evolution] because otherwise all the archeologists and people that did for all these skulls, their work goes to waste, because if we don’t learn about it now, nobody’s ever going to get into that career. And then the whole career is just going to end. And, I think...that career needs to keep moving because this evolution is extremely possible. I mean we could learn more about it. - Because they may never even know these [hominins] exist until later on in life. Which if they wanted do a certain job like you never know how it’s going to relate, and it could be that they have no clue about these [hominins] and then it

		ends up being in their job. • And instead of reviewing stuff that we had already known, we got to work on stuff that could really help us in the future...deciding what career we want to work on.
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Summary and Corroborating the Post Focus Group Data

The inductive analysis of the post focus group interview data, suggested that the hominin skull learning experiences helped student-participants achieve both positive affective and cognitive outcomes. Students attributed positive and emotive language to learning about human evolution through 3-D skulls. They demonstrated increased knowledge and understanding in regards to hominin evolution and the nature of science, and demonstrated increased abilities of inquiry (i.e., posing scientifically oriented questions, giving priority to evidence, and linking explanation to evidence). More specifically, students increased their awareness of the foundational and critical relationship between observation and inference. Last, the rich description shared by student-participants during the post focus group interviews (description steeped in the language of paleoanthropology) suggested that students engaged in authentic (Rule, 2006) and situated learning (Lave and Wenger, 1991).

The strength of these claims are enhanced when looking at other data sources:

- The extinct skull pre/post anticipation guide also suggested that students enhanced notions of the NOS (i.e., the notion that our knowledge of evolution is empirically based) (Table 4.39).
- The extinct skull presentations supported the claim that students engaged gave priority to evidence, and distinguished between observation and inference (Figure 4.1).

- The extinct skull drawings supported the claim that students generated their own scientifically oriented questions, gave priority to evidence, and distinguished between observation and inference (Figure 4.3).

The three data sources summarized above also support the notion of students participated in a community of practice, with fellow fledgling paleoanthropologists.

Final thoughts regarding curricular and methodological modifications are also required in this summary. One curricular modification deals with more explicit attention to NOS concepts. NOS concepts were explicitly discussed during learning experiences, however, these conversations were more teacher oriented than student oriented. So, learning gains might be achieved if students directly grappled with NOS concepts, such as the tentative nature of science. For instance, the Hominin Hallway Phylogeny learning experience might have students compare and contrast their own phylogeny with phylogenies of their peers or the experts. Desilva (2004) challenged his learners to make similar comparisons. Or student-participants might have to modify their phylogeny given one or more new fossil finds. Summarizing activities that challenge students to relate science as tentative to this learning experience could then be implemented. A second curricular modification would contain a learning experience regarding natural selection, but in the context of hominin evolution. Students might then gain a more holistic and balanced view of human evolution, merging both macroevolutionary and microevolutionary processes.

Reflecting on Teaching and Learning

In this final section of this results chapter, I would like to address one of my major research questions, “How do my conceptions of teaching and learning of human evolution

change during the study as I engage in teacher research?. Several of my conceptions have changed. Others have been substantiated.

In general, I maintain that teaching and learning is one of the most challenging, rewarding, and creative endeavors in which a person can engage. Teaching and learning is truly an art form and a science. One must be able to conceive learning themes relevant to students' lives, masterfully weave standards together toward meaningful instruction, respond impromptu and reflexively to student feedback, stay responsive to current research, efficiently complete administrative tasks, etc. After seven years of practice as a 7th grade science teacher, I have much room for improvement. However, I perceive that successful curricular interventions rest in a large part, on the motivation and dedication of the teacher to actualize and scaffold innovative instruction. Teachers must have an overall spirit of inquiry and exploration, seek rich experience, provide scaffolds for success, expect authentic performance, and give students space to construct their own knowledge.

More specifically, my conceptions of teaching and learning about human evolution have evolved. The results of the NOS scaffolding unit suggested that students adopted more absolutist views of science, a result of my emphasis on science as empirically based (evolution as empirically-based), and a reflection of my anticipation of student resistance to learning about human evolution. I think my concerns of student resistance were inflated, perhaps due to my own readings regarding the perceived conflict between evolution and religion, and the Christian conservative location of my study. Students demonstrated that they were open to learn about human evolution, in contrast to adults (even politicians) who publicly demonize the topic (Coltrain, 2012). This study supports the notion that students want to learn about their human

past, as also reported in earlier articles on the teaching and learning of this topic (e.g., Nickels, 1987).

I would definitely make some curricular adjustments. I would maintain a separate and distinct unit on the NOS. However, I would more carefully teach NOS concepts in tandem, such as science is empirically based, yet science as tentative, value-laden, and sometimes done poorly. I would also require students to explicitly reflect on nature of science concepts throughout instruction, requiring that I design more student-centered summarizing activities. Other major curricular improvements would include a) focusing on micro-evolution or natural selection using the human clade as an example--to holistically represent evolutionary theory, and b) remaking the student activity of creating and justifying a hominid phylogeny into a performance task—representative of its central importance in the practice of paleoanthropology.

Completing this dissertation has also convinced me of the power of using the hominin example as a vehicle for thematically teaching evolutionary theory, for engaging students in the essential features of inquiry (NRC, 2000), and challenging them to grapple with the nature of science. I don't think another example of evolution could deliver such comprehensive impact. Which other example could: relate to students' lives, provide a fossil record rich enough for comparative anatomy and phylogenetic analysis (and replicas of such fossils for classroom use), illustrate both micro and macroevolutionary processes, and connect to issues of our human present (e.g., mutation and HIV/Influenza) and human future (e.g., the intersection of global climate change and human evolution). So, I stand now with other educators who have also discovered the power of teaching evolution through human evolution (e.g., Nickels, 1987), but I am even more convinced given the student-generated data this study has produced.

Finally, the outcomes of this study must be considered within the climate of education and politics. The current education climate rewards knowledge over understanding (i.e., application, justification, sense-making, and making connections) (Smith & Siegel, 2004). High stakes testing events currently designed to give quantitative feedback (which is also quick, convenient, and standardized) often drive teaching and learning to covering a laundry list of standards, rather than implementing creative, thematic curricula as is the case of this study. If effective science curricula are to be implemented, then assessment procedures must also adapt. Karen Ostlund (2012), the current president of the National Science Teachers Association concurs. Ostlund (2012) argues for the integration of performance assessments with standardized testing, which would drive instruction toward engaging students in authentic practices of science.

Implementing the curriculum in this study (requiring extensive instructional time) before standardized testing may present challenges to teachers. I have thought about how the curriculum in this study might be divided up and implemented during the school year, so that students can benefit from this important curriculum before testing, while not interfering with mandated scope and sequences that teachers are required to follow. Addressing the NOS could occur the first few weeks of school, perhaps with an activity like the mystery box (Thomson & Beall, 2008), which relays concepts such as science as empirically-based yet tentative, and explicitly requires students to distinguish between observation and inference and base claims on evidence. These concepts could then be explicitly revisited during every subsequent science lab, investigation, or experiment. The extant skull learning experiences might fit neatly within the context of ecology, as feeding roles and relationships are one of the central features of this curriculum unit, and the study of mammalian teeth can be used to infer these feeding roles and relationships. Last, the hominin skull learning experiences could be implemented during the evolution unit, and the

human example could be used to cover requisite evolution learning objectives. However, additional learning experiences would need to be added, such as human evolution and natural selection, in order to teach and learn the necessary objectives before standardized teaching.

Finally, I have thoroughly enjoyed these explorations in paleoanthropology, alongside 7th grade students, fellow secondary science teachers, professors of education, and professors of paleoanthropology. I hope fellow practitioners are as lucky as I have been, so take such a rewarding journey in the discipline of science, and in a broader community of practice.

CHAPTER 5

DISCUSSION AND CONCLUSION

Introduction

I discuss two areas in this last chapter. I:

1. List the major claims that I make based on corroborating data, and make final conclusions regarding these claims, and
2. Assess the validity of my study using the validity criteria for action research set by Anderson and Herr (1999) and Herr and Anderson (2005).

Final Claims: Final Conclusions

The very last table (Table 4.43) of this research study lists the final claims I make regarding the use of 3-D hominin skulls to teach middle school students about human evolution. I make seven claims. The use of hominin skulls (and/or extant mammalian skulls) to teach human evolution:

- Enhanced learners' motivation to learn,
- Successfully addressed student alternative conceptions
- Engaged learners in the essential features of inquiry (NRC, 2000),
- Enhanced student knowledge (Bloom et al., 1957) of hominin evolution,
- Enhanced student understanding (Smith & Siegel, 2004) of hominin evolution,
- Enhanced learners' views of the NOS, and
- Situated learning in the context of extant mammology and paleoanthropology.

I supported these claims with corroborating data (Table 4.43), contributing to a) the overall trustworthiness of data (Freeman et al., 2007; Lincoln & Guba, 1984), and b) outcome and process validity (Anderson and Herr, 1999; Herr and Anderson, 2005) discussed in more detail in the following section.

My findings are significant for several reasons. First, they are significant given the new Next Generation Science Education Standards (NGSS) (NRC, 2012) which continue to emphasize a) evolution as one of four core principles of K-12 life science instruction and b) inquiry as central to scientific practice. So, the effective and empirically based curriculum that I outline in my study may be a viable curriculum to apply in secondary science classrooms. However, my curriculum addresses important concepts not emphasized by the NGSS, but considered significant in the science education research community. Like other scholars in science education (e.g., Smith 2010a & 2010b), I support evolution as one of the four core principles of a life science education but think the standards are lacking regarding emphasis of human evolution and related concepts such as macroevolution and phylogenetics. Science education scholars (Catly, 2006; Catley et al., 2012; Southerland & Nadelson, 2012) have argued for a balanced presentation of micro and macroevolution, but the NGSS do not appear to represent this balance. In line with current science education research (e.g., Beardsley, Boom, & Wise, 2012) the NGSS emphasizes inquiry, but under the dimension of scientific and engineering practices. Inquiry skills such as obtaining, evaluating, and communicating information are emphasized. However, standards regarding explicit attention to the NOS are not in the NGSS, and learning experiences in the NOS are pivotal in students learning about evolution (Southerland & Nadelson, 2012).

The findings in this study are also significant given calls made by the science education community for an evolution curriculum that a) is effective and empirically-based (Smith, 2010b; Beardsley, Boom, & Wise, 2012), b) addresses both the affective and cognitive domain of learning (Anderson, 2007; Dole & Sinatra, 2008; Southerland & Nadelson, 2012), and c) emphasizes macroevolutionary concepts (Catley, 2006; Smith 2010b; Catley et al., 2012).

I conclude by saying: This study responds to the new NGSS standards and informs gaps in the science education literature, increasing outcome and catalytic validity, which is discussed in the next section.

Table 4.43

Final Claims Supported by Corroborating Data

Claims: The use of extant and hominid 3-D skulls...		Corroborating Data
Enhanced learners' motivation to learn		• Extant skull focus group data (Table 4.12) • Hominid skull focus group data (p. 254-260)
Engaged learners in the essential features of inquiry (NRC, 2006)	Learner engaged in scientifically oriented questions	• Daily essential questions (Table 3.1) • Skull drawings (Figures 4.2 and 4.3; Tables 4.14) • Extant skull focus group data (Table 4.13) • Hominid skull focus group data (Table 4.30) • Independent Research (p. 288)
	Learner gave priority to evidence	• Extant skull performance task (Figure 4.1) • Hominid skull performance task (Figure 4.1) • Hominid skull focus group interviews (Table 4.31) • Student reflections (Table 4.15)
	Learner formulated explanations from evidence (inferences from observation)	• Extant skull performance task (Figure 4.1) • Hominid skull performance task (Figure 4.1) • Extant skull focus group interviews (Table 4.13) • Hominid skull focus group interviews (Table 4.31) • Student reflections (Table 4.15)
	Learners communicate and justified explanations	• Extant Skull Performance Task (Figure 4.1) • Extinct Skull Performance Task (Figure 4.1) • Hominid skull focus group data (Table 4.35) • Student generated hominid phylogeny and justification (Figure 4.4)
Enhanced student knowledge of	Extant mammology	• Extant skull focus group interviews (Table 4.16) • Extant skull performance task (Figure 4.1) • Teachable moments (p. 210)
	Hominid evolution	• Hominid skull focus group interviews (Tables 4.23, 4.32, 4.33, 4.34, 4.35, 4.36, 4.37, 4.38) • Hominid skull performance task (Figure 4.1) • Teachable moments (p. 212)
Enhanced student understanding of	Extant mammology	• Extant skull focus group interviews (Table 4.16) • Extant skull performance task (Figure 4.1)
	Hominid evolution	• Hominid skull focus group interviews (Tables 4.33, 4.34, 4.35, 4.36, 4.37, 4.38) • Hominid skull performance task (Figure 4.1) • Student generated hominid phylogeny and justification (Figure 4.4)
Successfully addressed alternative conceptions	• Hominid skull focus group data (Tables 4.24, 4.25, 4.28, 4.29) • Teachable moments (p. 212) • Student reflections (pending)	
Enhanced students views of NOS	• Hominid skull focus group interviews (Tables 4.38 & 4.40) • Student reflections (Table 4.39) • Teachable moments (p. 210 & 212)	
Situated learning in	extant mammology	• Description of extant skull learning experiences (starting on p. 83) • Extant skull performance tasks (Figure 4.1) • Extant skull focus group data (Tables 4.12-4.17 & Figure 3.10) • Teachable moments (p. 210)
	paleoanthropology	• Most all tables and all figures • Teachable moments (starting on p. 210)

Assessing the Validity of this Study

Anderson and Herr (1999) and Herr and Anderson (2005) have identified outcome, process, democratic, catalytic, and dialogic validity (Anderson and Herr, 2005, p. 55) as criteria for assessing the trustworthiness of teacher research. However, they (Anderson & Herr, 1999; Herr & Anderson, 2005) do not provide any useful rubric to use in order to determine the degree of a particular type of validity along a continuum. Below, I discuss each of the criteria separately, and how my research measures against such criteria.

Outcome Validity

Outcome validity assesses the extent the a) practitioner researcher answered their original question(s) or solved their original problem(s) (Anderson & Herr, 1999), and b) achieved action oriented outcomes (Herr & Anderson, 2005). I think this study achieved commendable outcome validity in regards to answering my research questions and providing new knowledge. However, more time is needed to determine the extent of outcome validity in regards to action-oriented outcomes. I begin by assessing the extent that I answered my research questions:

1. What affective outcomes are expressed when students apprentice as paleoanthropologists?
2. What student views of the Nature of Science are communicated as they apprentice as paleoanthropologists?,
3. What student abilities of inquiry are demonstrated as students apprentice as paleoanthropologists?,
4. What student knowledge of hominin evolution is communicated as students apprentice as paleoanthropologists?, and

5. What student understandings of hominin evolution are demonstrated as students apprentice as paleoanthropologists?
6. How do my conceptions of teaching and learning of human evolution change during the study as I engage in teacher research?
7. How should the curriculum intervention be modified based on teacher and student data sources?

As I look over 42 tables/frameworks I presented in my results chapter, I feel confident that data answered research questions dealing with both the affective and cognitive domains of student learning (i.e., research questions 1-5). My data collection methods (such as focus group interviews) allowed me to unpack diverse viewpoints, summarize general experience, and gain a panoramic view of classroom phenomenon. However, other data collection methods might have been needed to more effectively describe the impact of instruction at the level of the individual, and focus in on particular aspects of research questions (i.e., learning of macroevolutionary concepts). Case studies, focused on the experiences of three to five students, might have allowed me to gather more in-depth data regarding how individual conceptions were changing throughout the study. Also, validated measurements, like the MUM (measurement of understanding of macroevolution) (Nadelson & Southerland, 2010), may have allowed me to make more valid claims regarding my curriculum intervention on student learning.

The outcome validity regarding research questions six is less robust, because I think that my results section focuses more on student-generated data rather than on my reflections. This may be the case given my upbringing in positivistic paradigms of thinking. It did not seem objective or natural to switch from discussing student-generated data, to infusing my own personal reflections. Also, I did not keep extensive field notes and reflections during the data

collection process, as my commitments to teaching and other data collection methods required extensive amounts of time. Most of my reflection occurred post hoc, during data analysis, which has benefits according to Freeman et al. (2007). Reflecting on data after having distance from data collection provides refreshed perspective. However, more extensive field notes and reflections would have provided important perspective and context to learning events.

The outcome validity of research question number seven, regarding how I the curriculum intervention might be modified is considerable, as my suggestions regarding curricular modifications are infused throughout the data analysis and discussion sections of this study.

Last, I must comment on the degree in which my study has achieved action-oriented outcomes. I think it is too difficult and early to tell. First, I hope that my efforts made long-lasting impacts on my students. I hope that learning experiences broadened them, changed them, and influenced them. I hope that students gained a better sense of the NOS and gained key knowledge and understandings of evolution, as an education in science would require (Smith & Siegel, 2004). More importantly, I hope that these learning experiences helped my students to develop the habits of mind of science and life-long learning (Dewey, 1938), as a meaningful science education would do (Dewey, 1916). Perhaps the spirit of inquiry and curiosity engendered by learning experiences, followed my students in their future science coursework, influenced them to want to know more about their human origins, or introduced new epistemological perspectives. In other words, perhaps my students engaged in “transformative experience” because they “actively use science concepts to see and experience their everyday world in meaningful, new ways” (Pugh, Linnenbrink-Garcia, Koskey, & Stewart, Manzey, 2010, p. 2). However, I have not followed my student-participants and conducted any delayed data collection to measure prolonged impact. So claims regarding action oriented impact on students

cannot be honestly made, at least at this time. Given permission by the participating school system in this study and by my university's Internal Review Board, I plan on conducting several focus group interviews with student-participants who are not seniors in high school.

My major professor may be able to attest to some potential action-oriented outcomes of my research. I hope my research will help him, as he continues to be dedicated to implementing our curriculum with secondary school learners of science. I await his overall feedback.

Any other action-oriented impact is personal, but perhaps the greatest. As I hope for my students, I have been broadened, changed, influenced. I have been able to explore the curriculum design principles described in this study, and am convinced of their power to incite student motivation and situate learning in the spirit of relevant scientific practice. I apply some of these curriculum design principles (such as inquiry) with my own children to explore nature around us (like the ant colony under our front door stepping stone). I will continue to use these curriculum design principles as I engage in teaching and learning in the future—whether with other preschool students at my child's daycare, or with pre-service or in-serve science teachers at a college or university.

I have learned that risk-taking and pushing the envelope pays off. I think I took risks in implementing this curriculum with my students, because of the perceived conflict of religion and evolutionary theory, and given the conservative nature of my school and community. I learned what students can do with such a curriculum, and because of this, I have thought that teachers (and adults in general) are often the limiting factors in schooling, as they assume what students know or should know, and what students should do or be able to do. My students have amazed me with their openness and excitement to learn. I intend to continue to question tradition/push the envelope regarding teaching and learning.

I want to publish my findings to share with the science education community. So, potential for action-oriented outcomes exists, if my work is accepted, published, read by fellow practitioners, and ultimately has meaning for these practitioners.

In sum, I think that I have partly assessed the outcome validity of my study. I have or intend to answer my research questions, but it seems impossible or too soon to assess whether the efforts of my study will have action-oriented impact(s) on others.

Process Validity

I think aspects of this study achieved commendable process validity. Process validity assesses the integrity of the research methodology and research methods. The assessment of process validity might determine the extent in which the research was produced through a series of reflexive, recursive cycles--each adjusting and improving upon the next. Process validity might also determine the strength of evidence in terms of the triangulation of data and inclusion of multiple perspectives (Anderson & Herr, 1999; Herr & Anderson, 2005).

The culmination of this dissertation resulted from eight years of collaboration with my major professor. Many cycles and sub cycles of problem development, curriculum development, data collection, data analysis, and reflection occurred during these eight years and in different settings. My 7th grade classroom was used as a testing ground for our curricular ideas. In 2004, we implemented a “Virtual Gorilla” curricular unit introducing students to the nature of science through the study of Dian Fossey and the Mountain Gorilla. In 2006, we began implementing an early version of the curricular intervention in this study. Our inquiries about gorillas, led us into inquiries about hominid evolution. I conducted a pilot study in 2007, although not thoroughly documented. I conducted focus group interviews with students, and used these data to inform my teaching and research methods. Concurrent with our explorations in the classroom, we conducted

three staff development workshop and presented our ideas at local, state, national, and international conferences. These experiences with colleagues helped us to conceptualize what we were doing, reflect on what we were doing, and gain important feedback from fellow practitioners.

I did not spend the time between 2008 and 2012 in the 7th grade classroom. My time was spent as a graduate student completing coursework and graduate assistantship duties. More importantly, it was a time to delve into the literature and begin analyzing my data. I consider this time as a part of the cyclic and recursive process of teacher research. Progress was made with my research study, but this process was far from linear. Coursework with Dr. René Bobe, a renowned paleoanthropologist, encouraged me to think further about my curriculum intervention and the NOS in the specific context of paleoanthropology. The analysis of data in my qualitative research classes forced me to re-evaluate my research questions and supplement the literature review. Going back to the literature review then influenced my own interpretive lens during data analysis. A description of this reflexive, iterative process could continue. But the overall idea maintains that my research study has achieved a commendable level of process validity, as it has evolved over a considerable amount of time, with considerable effort, and considerable input from various perspectives (i.e., middle school students, high school students, in-service teachers, pre-service teachers, and college professors).

Process validity could have been improved by having stronger data collection methods such as validated NOS and evolution understanding measurements, or measurements containing more specifics about practices in paleoanthropology.

A second level of process validity assesses the strength of evidence by evaluating the extent in which the data have been corroborated. I think my study has achieved substantial process validity in terms of triangulating data (Table 4.43).

Democratic Validity

This study achieved more democratic validity in some areas than others. Democratic validity assesses the extent in which multiple voices were used in the research process, so that the results are relevant to the local setting. I think that this study had more or less democratic validity depending on the phase of the research process.

A considerable number of voices contributed to the development of the curriculum intervention as described in the previous section. This suggests democratic validity and the potential for my curricular intervention to have similar impact in similar settings. My curricular intervention might seem viable to fellow practitioners. I plan to check with fellow teachers to try to assess this viability.

The data collection process, however, had room for improvement regarding democratic validity. A total of thirty-four student-participants contributed insights during the data collection process, which is a substantial sample size for qualitative research. However, all of these student-participants were in 7th grade and were labeled as “gifted”. Including student-participants representing other grade-levels and demographics would provide multiple perspectives, rendering more viable and transferable findings. Readers may perceive the findings I share in this study, as relevant to 7th grade gifted students only.

The data analysis portion of this study also achieved less democratic validity, as my major professor and I were the only two people who analyzed the data. Member checking of data and having the data analyzed by more people representing diverse perspectives (e.g., secondary

science teacher, science education professor) would increase democratic validity. Putting these validity measures into place could be achieved in future research cycles, with better planning and willing participants

Catalytic Validity

I think my study has the potential to achieve considerable catalytic validity. Catalytic validity assesses the extent in which the research catalyzes thinking, discourse, action and future inquiry (Anderson & Herr, 1999). If catalytic validity is achieved then all participants (researcher and student-participants included) are transformed by the research process and are moved to take future action in some way. And, others in the local setting (i.e., science education community) might also be moved by the findings of the study.

As discussed in the section on outcome validity, I hope that my students reached “transformative experience” (Pugh et. al 2010, p. 2) because of our learning experiences, and that learning about their human past moved them in some way, changed their thinking in some way, so that they interact in the world differently than before. However, I have not conducted any delayed assessments to measure transformative experience and/or catalytic validity.

In the outcome validity section, I also discussed how I think my study will impact my future action, so I will not reiterate that here. However, I do think my study has the potential to catalyze conversation in science education circles for several reasons. First, my study still remains the only empirically based study of secondary students learning about hominid evolution using 3-D hominid skulls. Beardsley, Bloom, and Wise (2012) recently wrote a book chapter summarizing the research on effective evolution curricula. According to their review (Beardsley, Bloom, and Wise 2012), a) effective middle school curricular studies (n=2) focused on natural selection and general evolution, b) and effective high school curricular studies (n=9) focused on

natural selection (n=7), geologic time and macroevolution (but no human evolution) (n=1) and general evolution (n=1). My study definitely fills a gap in the research regarding the outcomes of a human evolution curriculum.

Beardsley, Bloom, and Wise (2012) also made suggestions for the development of effective secondary evolution curricula. They (Beardsley, Bloom, and Wise, 2012) suggested that effective curricula strategically weave inquiry-based, collaborative, and conceptual change teaching and learning strategies for optimal learning outcomes. Moreover, the teaching and learning of evolution should be made relevant to students lives, and students should be given ample time to construct meaning of this topic (Beardsley, Bloom, and Wise, 2012). I think my study answers this call. I also think that my study provides original insights regarding effective teaching and learning strategies, such as using 3-D skulls and human evolution as both a motivational tool to fuel and maintain learning, as well as helps deliver a strong cognitive message that is relevant to students' lives.

Dialogic Validity

I think this research study has achieved some dialogic validity, but has the potential to achieve more dialogic validity. *Dialogic validity* assesses the extent in which the research passed through a process of peer review (Anderson and Herr, 1999; Herr and Anderson, 2005). As in assessing democratic validity, dialogic validity varies depending on the phase of the research process. The curricular development phase of the research process went under considerable peer review a) during collaborations with practicing teachers to implement the curriculum, b) during three summer staff development workshops with secondary science teachers c) during over fifty local, state, national, and international conference presentations, and d) as a result of two peer reviewed publications (Thomson & Chapman, 2004; Thomson & Chapman-Beall, 2008).

The peer review process occurred less during the data collection and data analysis phases of my research study. I collected the data in my classroom, and by myself. During data analysis, however, my major professor provided useful feedback when checking my coding procedures. This final stage of my research, defending to my dissertation committee and publishing my findings, will provide additional opportunities for peer review, and subsequent determination of the degree of dialogic validity reached in my study.

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