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UNDERSTANDING THE NATURE OF SCIENTIFIC LANGUAGE: HOW FOUR COLLEGE STUDENTS VIEW EVOLUTION

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UNDERSTANDING THE NATURE OF SCIENTIFIC LANGUAGE: HOW FOUR COLLEGE STUDENTS VIEW EVOLUTION

by

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Dedication

For God and my loving husband, Andre

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UNDERSTANDING THE NATURE OF SCIENTIFIC LANGUAGE: HOW FOUR COLLEGE STUDENTS VIEW EVOLUTION

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The University of Texas at Austin, 2011

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Despite the wide-spread acceptance of evolution within the science community, much of the public still holds reservations about evolution as a valid scientific explanation. This is due in part to questions regarding the very *nature* of a theory, which has been cited by many researchers as an obstacle to accepting evolution. The specific use of semi-structured interviews and research into how students view other nature of science terminology (fact, hypothesis, and law) in relation to theory may provide further insight into how use of the terms can frame attitudes towards evolution.

This study qualitatively describes how four college-aged students (science, philosophy, education, and business) interpret basic science terminology and compare scientific explanations in their assessment of evolution. While discussing the terms, students were encouraged to raise other issues that aided them in the construction of their epistemological beliefs about science. The aim was to provide interviewees with the

opportunity to speak openly about what they understood regarding nature of science and evolution rather than presuming a shared coherence in the use of the terms.

The semi-structured interview format revealed students' conceptions (or misconceptions) of the nature of science, relative degrees of certainty for the terms, and underlying biases. The results suggest the specific use of interviews can provide a credible and informative account of how students use basic science terminology. A mixed use of the terms can still lead to a favorable disposition towards evolution when students possess a positive attitude towards science, acknowledge the tentative nature of science as a strength rather than a limitation, and practice reflective reasoning. Conclusions made in the study also suggest that an explicit discussion about fact, theory, law, and hypothesis in the science classroom may actually play less of a critical role than previously thought in opening the door to learning content of which many people consider to be controversial. More concentration should be placed on how knowledge is generated and how to reflectively approach a scientific problem.

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CHAPTER 1

INTRODUCTION

After observing the struggle that secondary school students had with defining and using basic science terminology, I wondered how this would affect their appreciation for scientific work as it was presented in the textbooks and online sources. How was it that there were so many interpretations for terms (fact, hypothesis, law, theory) that had been introduced to them since the elementary grade level? What was it that was causing for the meanings of these terms to evolve? Did it affect how they would compare ideas, weigh evidence, or solve problems?

My interest in learning and background in biology led me to wonder whether the transition from high school to college really made much difference in the development of scientific thought. It is generally expected that the more intensive coursework and unique peer interactions found in a university setting is meant to help students think through problems more deeply and to re-evaluate decisions. When I was given an assignment during my first summer of graduate coursework to go and interview someone on a question of particular interest to me, I chose to revisit the question on basic science terminology. That preliminary interview opened up more questions for me about what people really knew about science and prompted me to continue research in this area. Would I be able to find a pattern for meanings and uses for basic science terminology among college-aged adults?

Background

In evaluating student conceptions of science, it is the basics that require the most attention. We tend to divert attention to the more complex, the abstract, or the most feasible when discussing concepts with students in the classroom, but there is a surprising majority that desire to revisit the basics. The question is *why*. Without a thorough exploration into the language of science and an explicit discussion of basic terminology (fact, hypothesis, law, theory), the likelihood of multiple personal constructions of meanings arise. Furthermore, establishing common meanings may lead to improved communication of ideas, which can lead to a diminishing of misconceptions and increased appreciation of more complex issues such as evolution (Alters & Nelson, 2002).

Within the science and science education communities, evolution is considered the central unifying theme for studying biology (Dobzhansky, 1973; National Academy of Science [NAS], 1998). Dobzhansky (1973) asserts that nothing makes sense in biology without the light of evolution to illuminate how all living things are interrelated. Even with such agreement within the science community, the majority of the public continues to doubt the explanations offered by evolution and views the subject as a controversy (NAS, 1998; Rutledge & Warden, 2000). This can be traced to the belief that acceptance of evolution would equate to a rejection of personal religious convictions (Brickhouse, Dagher, Letts, & Shipman, 2000). The creation-evolution debates have been centered around the validity of evolution and the language that is used to describe it. While some may consider evolution as only a theory and discredit its existence, Ernst

Mayr (2001) has responded to this by giving evolution the status of a fact. The varying terminology that is used has created much confusion, which has led to evolution's continual position at the forefront of conversations related to curriculum and effective pedagogy (Goldston & Kyzer, 2009). Decades of public polling (Miller, Scott, & Okamoto, 2006) consistently reveal the same message: the layperson does not value evolution in the same way as the scientist.

Due to the on-going battles of how to adequately portray evolution, it is vital to find a common language to describe not only what evolutionary theory is but to also determine how it broadens understanding in biology. How a person assesses, compares, and evaluates scientific evidence depends on one's working understanding of the process of science (Rudolph & Stewart, 1998; Rutledge & Warden, 2000). An understanding of the nature of science, then, is a key component in science education reform and contributes to the development of science literacy (American Association for the Advancement of Science [AAAS] 1993; National Research Council [NRC] 1996). To be scientifically literate means that one can understand how science knowledge is constructed rather than only being able to recall memorized information.

There have been a wide set of perspectives regarding what NOS should ultimately include, how to teach NOS in the classroom, and how to assess student conceptions of NOS (Lederman, Abd-El-Khalik, Bell & Schwartz, 2002). Regardless of the differences, though, scientists, science educators, and historians and philosophers of science have focused on NOS because they perceive a link between NOS knowledge and a deeper appreciation for evolution. By examining individual perspectives on nature of science through the way they use basic terminology and interrelated epistemological beliefs, it is possible to more closely determine what shapes students' attitudes towards the theory of evolution.

Purpose

The purpose of this study is to qualitatively determine how four college-aged students perceive basic science terminology (fact, theory, law, hypothesis) within the familiarity of their own discipline (science, philosophy, education, and business). There is much written in the literature about how essential it is to share a common use of the terms, but no empirical evolution studies that show how students from different disciplines interpret these words and whether this could influence their perspectives on evolution. By tracing the line of reasoning for individuals who think about very different kinds of problems, science educators can gain insight into the shared influences that shape the minds of scientists and non-scientists when they examine scientific issues. Does this thinking change when applied to controversial topics like evolution? Conclusions made from individual perspectives will contribute to education research on nature of science and evolution by providing direction for more effective pedagogy and instructional strategies that can be implemented in the classroom.

Research Questions

The research questions that are guiding this study are:

1. Can interview methodologies be used to give a credible and informative account of how 4 interviewees use theories, facts, laws, and hypotheses?

2. How do students' interpretation of these terms frame attitudes and accounts of evolution as it is used in biology?

Organization of the Study

Chapter 2 includes a review of the literature regarding nature of science, specifically its importance and relationship to science literacy in general and evolution in particular. Chapter 3 introduces the research design, methodology, and ways of establishing trustworthiness. Chapter 4 presents the results and data analysis along with a summary on attitudes towards the theory of evolution for each participant. Chapter 5 discusses findings, implications, limitations, future research, and pedagogical applications.

CHAPTER 2

REVIEW OF THE LITERATURE

General Evolution Situation

Evolution is generally described as how living organisms share common ancestry with those from which they are derived (National Science Teacher Association [NSTA], 1997). Professional scientists and science education associations consider evolution as a central unifying principle within biology (AAAS, 1993; NAS, 1998; NRC, 1996; NSTA, 1997) because it provides explanations for how living things have changed across all biological disciplines. It is crucial, then, to develop an appreciation and understanding of evolution concepts.

During the last two decades, science educators have sought to identify the influences that have been associated with teaching and learning evolution (Deniz, Donnelly, & Yilmaz, 2008; Goldston & Kyzer, 2009). Research continues because of the low levels of teacher appreciation and understanding of evolution (Nehm, Kim, & Sheppard, 2009; Rutledge & Warden, 2000). The impact of a lack of appropriate evolution teaching in the classroom has reached high school students (Aguillard, 1999; Lawson & Worsnop, 1992), undergraduate students (Anderson, Fisher, & Norman, 2002; Ingram & Nelson, 2006), graduate students (Gregory & Ellis, 2009), and the adult population (Alters, 2004; National Academy of Science, 2008). Due to the varying outcomes within and across populations, it is difficult to track which variable (or combination of variables) will favorably dispose a person towards the theory of evolution.

Nature of Science (NOS)

To appreciate evolution, one must be able to compare the use of the scientific language as it is used in everyday living and in nature of science discussions (Smith, Siegel, & McInerney, 1995). Lederman (1992) defined nature of science (NOS) as the epistemology of science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development. Although there is much debate surrounding the more sophisticated nuanced aspects of NOS, Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) lay out a set of ideas that are generally accepted by science educators. Scientific knowledge is: tentative; empirical; theory-laden; partly the product of human inference, imagination and creativity; socially and culturally embedded. Three additional aspects are the distinction between observations (gathered through human senses) and inference (interpretation of those observations) in science, the lack of a universal scientific method, and the functions and relationships between scientific laws and theories. The latter part will be explored in this study.

Depending on the individual's background, evolution is either accepted or rejected due to one's appreciation for the label "theory". Those who accept it seem to understand the scientific meaning behind the term "theory" and knowledge of the scientific process; those who reject it seem to do so on the grounds of religious commitments (Brem, Ranney, & Schindel, 2003) or the need for "theory" to be replaced by a label that posseses a higher degree of certainty such as “law” (Alters & Nelson, 2002). The public frequently equates a theory to a “guess” or a “hunch”, which creates difficulties in evolution education (Smith, Siegel, & McInerney, 1995). Thus, it is important to know the relationship between theories and laws.

According to Lederman, Abd-El-Khalick, Bell and Schwartz (2002), students tend to hold a hierarchial view when considering the relationship between laws and theories. Students believe that with enough supporting evidence, theories can become laws, which implies that laws have a higher status than theories (McComas, 1996). The researchers pointed out the need to separate these ideas and emphasize that laws and theories are distinct kinds of knowledge. Laws are empirical statements that describe the relationship among observable phenomena (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) and are constrained by a set of conditions (Scott, 2005). Theories, on the other hand, have a dual function. They serve to explain large sets of observations as well as predict future occurrences. Theories and laws, then, do not become one another as both are equally legitimate ways of knowing (Alters & Nelson, 2002; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Because of the nature of scientific explanations and rigor of investigations that are implied behind the words, the science educator is led to believe that *there is an appropriate and inappropriate way to use the words*.

How NOS contributes to Acceptance of Evolution

If there is an appropriate way to use basic terminology, this suggests that the NOS problem is more than an issue of semantics. Terms like “fact”, “theory”, “law”, and “hypothesis” were cited by Smith, Siegel, and McInerney’s (1995) analysis of foundational issues discovered in evolution education. The authors recommend educators spend time explicitly discussing the scientific and non-scientific use of the terms, helping students to distinguish how the terms should be used in different settings. Theories are not merely “guesses” or “hunches” in the scientific world, but supported by evidence and possess high explanatory power. The authors believed the active use of the terms without an explicit discussion would continue to create an unnecessary misunderstanding among the public and threaten the credibility of good science like evolution. Dagher and BouJaoude (1997) echoed similar sentiments, supporting the exploration of epistemological questions related to the nature of the terms. The researchers suggested using the words in specific contexts as this would give students a more accurate meaning of how they are used in science as opposed to the vernacular use of the words. Scott (2005) also referred to the set of terms when advising science educators on strategies to use in improving their teaching on evolution. She pointed out the need for students to develop a shared meaning of the terms before they could begin to appreciate evolution. These researchers all indicated that if students knew how to think and use scientific language as a scientist, then the problem of evolution would be alleviated. In other words, *a shared coherence in the use of basic science terminology would lead to favorable dispositions towards scientific issues, including controversial ones such as the theory of evolution*.

While science content knowledge is important, Shamos (1995) pointed to an understanding of the NOS as a pre-requisite for achieving science literacy, which is a central goal of education reform (AAAS, 1993; NRC, 1996). Knowing how information is generated and assessed can be far more valuable than being able to accumulate a list of facts. An individual's understanding of the NOS can enhance his/her learning of science content, understanding of science, interest in science, and decision-making ability (McComas, Clough, & Almarozoa, 1998). Because of the potential impact in all of these areas, concentrating our efforts towards improving NOS understanding is hoped to improve the current evolution education situation as it situates the learner in a better position to examine the problem.

Limits of Quantitative Data

There is empirical research on evolution showing that as students develop a more sophisticated understanding of the NOS, they are able to identify the underlying assumptions involved, adequately compare concepts within science, and distinguish between knowledge frameworks such as religion and science (Settlage & Southerland, 2007). A student's firm grasp on NOS has been linked to significantly positive attitudes towards evolution (Johnson & Peeble, 1987). Similarly, Scharmann and Harris (1992) revealed that it is possible to change teacher attitudes towards evolution after exposure to NOS content, advanced evolution concepts, and the opportunity to discuss common problems associated with teaching evolution in the classroom. A more recent study done by Nehm and Schonfeld (2007), however, showed that after a 14-week intervention designed to increase NOS knowledge, teachers still preferred the inclusion of antievolutionary ideas in school. The results indicated that despite significant gains in

NOS understanding, teacher attitudes about evolution were not changed. Due to the conflicting results in these studies, it would be appropriate to inquire about dispositions using qualitative approaches where student conceptions and other epistemological beliefs could be more deeply explored.

Educators have long recognized students come to class with deeply held ideas based on prior learning on a variety of topics (Bransford, Brown, Cocking, 2003). Because of this, it is imperative to probe for student conceptions (and misconceptions) in the classroom to engage students at the level of their understanding (Verhey, 2005). Using this information, educators could then more appropriately help students to situate or reconstruct what they already know with the new knowledge that is presented. If the educator can successfully assist students in incorporating new information into their worldviews using this methodology, then researchers can adopt a similar methodology to achieve a similar goal. Adequate probing for student ideas cannot be restricted to a multiple-choice test or questionnaire based on a Likert scale, but requires a form of assessment that is much more open-ended for a fuller portrayal of what influences students.

Importance of Interview Methodology

The methods employed by science education research have not currently produced consistent results that can be used meaningfully by a science educator to form student attitudes towards evolution in positive ways. Attitude is conducive to future learning of content and continued appreciation. It is necessary, then, for the researcher to implement interview methodologies so that more fruitful information can be collected about issues that fall within the student's worldview. The use of semi-structured interviews in several other studies (Brem, Ranney, & Schindel, 2003; Dagher & BouJaoude, 1997; 2005; Hokayem & BouJaoude, 2008) have revealed interesting findings about college students' perspectives towards evolution because the data is shaped by the participants. The researchers in these studies have retrieved information related to nature of science, epistemological beliefs, religious beliefs, sociocultural influences, perceptions of nature and causality, and perceptions of the social and personal impact of evolution.

The reasons for accepting or rejecting evolution varied among individuals and currently fall into one or more of the following categories: complexity of concepts, religious commitments, and perceived negative social consequences. What is missing in the literature, however, is how students' specific use of basic terminology frames their attitudes towards evolutionary theory especially when they are "given the opportunity to discuss their values and beliefs in relation to science knowledge" (Dagher & BouJaoude, 1995). Retrieving such information would be helpful in being able to assess how students learn about topics that are considered controversial by the public.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

The purpose of this study was to explore how college-aged students reason and use scientific language to describe how they view the scientific process. It also examined how a student's interpretation of the scientific process can shape how evidence is evaluated, which then aids in understanding attitude towards evolution.

With this purpose in mind, the general guiding questions of the study were:

1. Can interview methodologies be used to give a credible and informative account of how 4 interviewees use theories, facts, laws, and hypotheses?
2. How do students' interpretation of these terms frame attitudes and accounts of evolution as it is used in biology?

Research Design

To acquire a holistic perspective of what students know about scientific processes and the theory of evolution, a qualitative case study approach was purposely chosen. The in-depth investigations were exploratory in purpose, allowing for each participant to bring in their own experiences and adequately representing individual thoughts pertaining to the topic. Instead of seeking to test self-generated hypotheses, the researcher sought to develop them as a result of interactions with participants during the interviews. By implementing this type of case study, the researcher minimized subjectivity in the process of data collection and was not restricted to a set number of variables.

There are several other advantages to using case study in evolution education research, as this is an area that is dominated by quantitative studies. The intention behind using a semi-structured interview format was to allow the researcher to more precisely record factors that influenced the *participants* rather than limiting the participants to forced-choice responses (and author biases) that are characteristic of questionnaires or surveys (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002).

Methodology

Participants

With the goal of acquiring data that would offer deep and interesting insight into the evolution education problem, an information-oriented sampling process rather than random sampling was taken to recruit the UT participants. There were a total of four college students; two students (science and education) volunteered to participate during a class visit; the other two students (business and philosophy) were approached on campus in front of their respective college.

Data were collected in the form of demographic surveys, field notes, audiotapes, and summative visuals. The demographics survey included questions about major, age, gender, biology background, science motivation, religion, and stance on the theory of evolution. The responses are shown in Table 1.

Table 1: Participants' Background Information

Major	Gender	Age	High School Background included:	Science Motivation Level (1-5)	Religion	Stance on Evolution
Science	Male	26	Evolution	5	Catholic	Very supportive
Philosophy	Male	26	Evolution	4	Catholic	Very supportive
Education	Female	27	Evolution	5	Catholic	Very supportive
Business	Male	25	Evolution	5	None	Very supportive

Interviews

Each student participated in a semi-structured interview that ranged from 1 to 2 hours. This type of interview allowed for specific information to be collected while still providing room for emerging questions or issues to be raised by the participant (Fontana & Frey, 2000). The interview examined students' meanings and intended use of terms (theory, law, hypothesis, and fact) to describe their views on scientific reasoning and evolution. The responses naturally led to a discussion about how the students' college major, upbringing, and nature of science knowledge helped to shape their epistemological beliefs about science. The open-ended nature of the questions allowed the students to express influences which dominated their thinking patterns. After a discussion about the level of certainty associated with each of the particular terms (theory, law, hypothesis, fact), participants were then asked to provide a visual diagram that represented how they compared the terms relative to importance to scientific reasoning. This was a way for the researcher to verify information as expressed by the participants.

The interviews took place at a time and place that was convenient for the participant, either at the UT campus or a local coffee shop. All meetings and correspondence occurred in the summer of 2011. In addition to field notes, all interviews were audio recorded to ensure the complete thoughts of each person and for future analysis. The tapes were transcribed verbatim within 24 hours. The semi-structured interview protocol is located in Appendix A. For sample interview transcripts, refer to Appendix B.

Data Analysis

The data were analyzed during and after the study was completed. Using an open system, the data for each participant were read several times to obtain a general sense for what the participant's biases were. What were the potential biases that may have led the participant to concentrate more on certain topics? What were the fears, and how did this affect what the participant was willing to share? Did the participant's thinking evolve over the course of the interview? How many times did the participant repeat certain ideas? Was the participant comfortable with the questions? Was there a laugh, a smirk, utterances of hesitation?

During the data reduction process, special care was taken to find characteristics for questions relating to the following: facts, theories, laws, and hypotheses. Specific points that were recorded were: description of meanings and use for the participant, description of how others defined or used terms, how terms were used in relation to other terms, how meanings evolved as a result of new situations, the influence of the participant's upbringing or major field of study, the participant's degree of certainty for the terms, the participant's need for certainty in general, the purpose and nature of science. All points were not displayed for each participant. A characteristic was outlined only if it was judged to be distinctive enough from other participants, and if it carried theoretical significance for the study.

Participants' responses were then assessed for similarities and differences. An attempt was made to cite the specific experiences that allowed for the similarities between participants, and for the experiences that set the participants apart. This information was then used to develop conclusions and make recommendations for future study.

Establishing Trustworthiness

Member Checking

To ensure that the data collected during the interviews were valid and credible, member checking was done during the interview. Due to the open-ended nature of the interview, it was expected that clarification of statements would be needed as ideas were revisited. Participants were asked to restate any confusing concepts and to provide various examples for those ideas that seemed contradictory to one another. While definitions of terms (theory, law, hypothesis, fact) mostly stayed the same, the use of the terms sometimes changed as the participants drew upon the different sources that shaped their way of reasoning. Member checking during an interview is important as it allows the participants to reflect on what they said, and to correct any misinterpretations by the researcher.

Another layer of validity was added at the end of the interview, where each participant was asked to draw a visual to represent their final stance on how the terms (theory, law, hypothesis, fact) should be ordered according to importance to scientific reasoning. The summaries captured the intent of the participants and provided the researcher with the confidence to determine the accuracy of the data.

After transcribing the interviews, participants were each given a copy to read and the opportunity to edit for even further clarification, or to remove any ideas that did not fully describe their thoughts. Overall, participants were happy with the results and felt the transcripts were a faithful representation of the interview that took place. Due to the subject matter and the rapport that was built, each participant expressed interest in being contacted if further information was needed.

Thick Portfolio Descriptions

By providing elaborate and thick descriptions of the discussion that took place during the interview, other readers can comment on the validity of the research conclusions. A person's comfort level, biases, and emotions cannot be captured by words alone (even if they are verbatim) so special care was taken to also record things like: pauses, repeated phrases, hesitation, laughing and moments of frustration. One of the participants commented, "I like how the document preserves my pauses and somewhat fractured sentence structure that resulted from me trying to speak about things I don't think about too often."

Peer Debriefing

To minimize biases by the researcher, the data were shared with the supervisor and an education graduate student. The researcher met periodically with the supervisor and graduate student to check for consistencies in the evaluations. The results were verified to see if what was transcribed reflected what was in the audiotapes. By sharing conclusions with people who were not involved in the study, the researcher was able to gain new perspectives and a different interpretation of the data.

Triangulation

To ensure the validity and credibility of the results, a methodological triangulation approach was taken in this qualitative study. Data were collected through demographics surveys, audiotapes, field notes and participant visuals. By combining several sources of data, students' thinking could be more fully and appropriately assessed. The individual methods alone would not have held the same weight or level of trustworthiness.

CHAPTER 4

RESULTS AND ANALYSIS

To better understand the data, each case study included: a background on the participant, the interview, participant visual, and a brief summary. The purpose of the background was to give the researcher a sense for who the participants were, where they came from, and their potential biases. To clarify interpretations and to capture participants' intentions, member checking was implemented throughout the interview. Finally, all participants were asked to construct a visual that represented the way they thought about and used: fact, theory, law, and hypothesis. No specific instructions were given on how to do this as it was up to the individual based on his/her experiences. The summary illustrated specific descriptions that were unique to each participant, making it easier to compare and contrast between individuals.

Shawn, "The Science Guy"

Background

Shawn recalled a love for the outdoors and exploring nature while he was growing up in his New England home. Shawn's mother was an artist and taught adults how to sculpt at a local school while his father taught history at a state university. Around the dinner table, Shawn's father often engaged the rest of his family in conversations that typically centered on ecology and environmental issues. Working hard in school was not uncommon for members of Shawn's family. Even though Shawn attended public school all of his life, he was placed in a special group of students who were exposed to a heavy emphasis of humanities and philosophical thinking. It was also during this time that Shawn completed his AP science courses, and where evolution content was first introduced. During his freshman year of college, Shawn joined a research team for one of his professors and found a home doing biological lab work. He applied to UT for graduate school and got accepted into the Ecology, Evolution and Behavior program. Like many of his friends, Shawn aspired to become a full-time researcher or research professor one day.

During the interview, Shawn was easily outgoing and enjoyed talking about what he did in the lab. Building models, he tested different theories on how patterns of sexual selection in fish and epidemiology directed patterns of genetic diversity. When we discussed public education, Shawn shared his hopes that the Texas State Board of Education would integrate more evolution time in the curriculum. He and several colleagues presented their ideas to several education committee members, but he felt it was to no avail. When prompted, Shawn commented on how his Catholic faith had never been a conflict in his pursuit of scientific activities. Shawn seemed to genuinely care about learning and sought opportunities to teach others about pseudoscience and how to avoid falling into misconceptions.

The Interview [1]

Facts

When I asked Shawn about facts, he divided his explanation into two groups: “formal definitions” (the one which is accepted by the general public) and “reality” (the one which he ascribes to). Shawn said that generally, facts are things people “just accept as true” and shouldn’t require further investigations. Most people consider facts to be infallible because of the nature of its definition (Driver, Leach, Millar, & Scott, 1996), but in reality, Shawn believed “facts can be wrong”.

Due to his worldview, Shawn comfortably accepted uncertainty as a part of the science package. He rationalized that if facts had the potential of being disproven, then **facts didn’t exist in reality**. Unlike the other participants, Shawn ventured to say “**Everything is really just a ‘theory’**. This stems from our misunderstanding...our general inability to deal with uncertainty. We *need* to have facts for things.” It was clear that Shawn felt some anguish as he understood the implications this would have on people if certainty did not exist. This same idea was articulated by Henry Pollack (2003), who expressed that people sought certainty for feelings of contentment. Instead of viewing uncertainty as something that paralyzed the scientific process, Shawn understood how uncertainty could be leveraged to promote the utility of science. For the scientist, uncertainty invited creativity and imagination.

Another interesting point in the discussion was when Shawn explained how a fact came to be. He said, “If something’s right 99% of the time, that *might* be enough for it to

[1] All bolded text in the “interview” section are researcher’s own emphases.

be a fact." For other situations, though, Shawn did not think that 99% was sufficient. Due to his years of observations as a researcher, Shawn was convinced that facts could be mutable but he was struggling with situating his own meaning for facts with the way it was generally accepted by the public. How apparent, I wondered, is the mixing of meanings when Shawn is analyzing data or discussing the importance of evidence with a group of students? How much is use and interpretation of scientific language influenced by one's understanding of the nature of science? Due to his acute sense for uncertainty, Shawn would've happily eliminated the term "fact" from his vocabulary when speaking about how science operates.

Theories

In response to what theory was, Shawn replied, "A hypothesis that has failed to be rejected many times." Shawn then began to characterize theories as "very well explored" and "open to further investigations". In other words, theories were testable. Shawn described how one can observe gravity in action when dropping a ball. Another way that theories could be directly tested is by taking a flask of media, inoculating it with *E. coli*, and waiting two to three days for it to colonize. The two examples that Shawn gave were indicative of his understanding of the nature of theories as **requiring direct evidence**. He did not provide any further examples of how theories could be tested indirectly, which was surprising given his deeper content knowledge of evolution.

"The theory of evolution is not the theory of evolution," Shawn insisted. He pointed out the need for people to specify which theory they were referring to. The problem is most people do not realize that there are multiple theories of evolution and that natural selection is only one mechanism. He went on with another example about gravity, stating "The theory of gravity is not the theory of gravity. It's the theory of how gravity acts upon falling objects or how gravity is impacting the motion of the object." Again, Shawn was using the word theory in a way that would allow someone to implement direct tests.

Shawn's personal definition of a theory. "A thing can become a theory and it remains a hypothesis through a series of evaluations and modifications but it is still a hypothesis." To Shawn, **theories and hypotheses appeared to mean the same thing**. Again, they were both directly testable. The difference was the amount of verifications that were done.

Can theories, then, hold a higher level of certainty than hypotheses? Shawn hesitated to respond as he perceived the process to be rather complex:

> One of the things that I'm interested in is how sex chromosomes evolve and we have hypotheses about the processes that may be important but then below that we would generate a specific question like "We think that process 'x' is operating on this chromosome." This species of fish we can then go out and test if there's evidence for that or not when certainly there is evidence for that. This provides evidence for a broader hypothesis, which then provides more evidence for a broader hypothesis. They are all nestled in each other…um, but if we find out it's not happening it doesn't mean that every other hypothesis above it is wrong. It probably means that some of them…there may be less certainty about. (Shawn, Interview, June 8, 2011)

Because **theories were "hypotheses nestled within other hypotheses**" in Shawn's worldview, it became even clearer why certainty could never be reached. While discussing levels of certainty may have caused other participants to question the validity of their own reasoning, it was unsuitable for Shawn since he maintained a strong understanding and appreciation of the scientific endeavor.

It is important to note that Shawn believed that other people in different specialties (even within biology) would probably disagree with the way he defined and used theories. This is a term that he did not generally use while working in the lab setting with other scientists. It was usually in interacting with non-science people, Shawn observed, that his supervisor spent a lot of time hashing out what he meant by the term. What was even more interesting, though, is how Shawn seemed to view the differences he had from his own supervisor as not mattering. While Shawn visualized a theory as a descriptive and explanatory statement, his supervisor visualized a theory as a mathematical model. Because theories are used for multiple functions (even outside of science), it is no wonder so much time is spent trying to explain them.

Although Shawn seemed eager to define theories and meanings at the beginning, his opinion evolved throughout the interview especially as it related to evolution education. Shawn had a firm and comfortable grasp of theories for himself, but made a comment that when other people start talking about theories, they have “left the realm of science” (mentions this twice) altogether. At this point in the discussion, though, Shawn was probably a bit exasperated and felt the study was “more of a philosophical discussion about truth and certainty.” Nonetheless, his daily lab experiences motivated him to include theory under the “science” category.

Hypotheses

"People like to do things in hierarchies – it's nice that way." Shawn recalled some high school memories and reflected on how his teacher taught them the scientific method. Although he did not support the stance that theories and hypotheses had differing levels of certainty, Shawn did emphasize that theories should be placed on a higher level than hypotheses due to the differing amounts of verification and evidence. For this reason, **theories would have more weight than hypotheses**. Shawn's understanding of the nature of theories and hypotheses allowed for him to place these terms on the same level for certain instances, but not for others.

From a teaching standpoint, Shawn did not seem aware of the ramifications that arose from saying "a theory is also a hypothesis about something". When Shawn was asked what he thought about students who equated theories to hypotheses, he did not see the underlying significance behind this state of reasoning (especially with the evolution debates) and felt it was ok for different people to have different interpretations. This was probably because Shawn assumed that the students who were doing this would interpret the terms in a similar way to him (theories and hypotheses would need to belong on the same level if theories are "hypotheses nestled within hypotheses"). Unlike Shawn who understood the complexity of scientific thinking, these students tend to describe theories and hypotheses similarly to show the weakness of theories in explaining evolutionary events.

It is important to note that had it not been for an extensive and engaging interview with lots of probing questions, Shawn's position on theories and hypotheses would have been easily blurred. Shawn may have sounded as if he thought the meanings were the same initially, but the elongated time gave him the opportunity to clarify how the two ideas reinforced one another in science. The difficulty with having conversations like these comes from the lack of time to fully and seriously assess individual ideas, which could be useful in being generalized for similar cases.

Laws

Laws were no longer used in modern day science. Because he did not hear them referenced in mathematical/experimental studies, Shawn described laws as "antiquated" and a "hold over from physics". Other physicists would probably agree, Shawn asserted, because exceptions have been discovered for phenomenon like gravity and motion. It wouldn't make sense, then, for laws to continue to exist. Instead, Shawn believed that it would be "**completely interchangeable and correct to call it a theory**" as there were no absolutes in nature. Again, Shawn emphasized his beliefs that the scientific reasoning process should be thought of purely in theories (or hypotheses) because of their tentative qualities. Facts and laws, on the other hand, would be dismissed because of the public confusion that has been created with the use of these terms since they tend to be publicly associated with a great level of certainty. This would be contrary to what is perceived as the nature of science, a place where disproving or eliminating hypotheses leads to an explanation for how something occurs rather than for reasons of gaining certainty.

Table 2: Shawn's Visual

Non-science:	**Science:**
Fact	Hypothesis → Theory
Law	

Summary

Shawn, a science researcher and teaching assistant, thought statements describing the natural world should be divided into "non-science" and "science" categories. He grouped terms under the "non-science" category if they 1) were rarely or never mentioned in the lab 2) were missing in science publications, and 3) appeared to have a high level of certainty (according to public perceptions). Facts and laws were both terms that did not belong to what Shawn would consider as the tentative nature of science. He gladly grouped these two terms as "non-science" because they were misleading people with how scientists actually proceeded with their work. He believed that in reality, people were discovering violations and exceptions all the time, which would explain why the term 'law' especially was no longer being used among scientists. Instead, it would be better to exchange "law" for "theory" as this move would more appropriately describe theories as being subject to change.

"The closer you look at something, the more you realize you don't know anything." Shawn discussed the value of critical thinking and the need to build a hypothesis first, which would help the researcher to build more hypotheses upon the first. After a series of testings and modifications, the hypothesis could become a theory (which was only to be distinguished from hypothesis due to the amount of evidence). Both hypotheses and theories, though, would still hold equal levels of uncertainty for Shawn as he saw this as the main ingredient for a "scientific" endeavor.

Andrew, "The Philosopher"

Background

Andrew was the youngest child in his family and attended a college prep school. He recalled an English teacher who taught him how to reason through his arguments and to articulate them on paper. Even though he expected to be a doctor one day, Andrew was strongly attracted to class discussions that involved a deeper exploration of ethics, theology and morality. He did not find the challenge that he was looking for in the science classes that he took (which did include evolution content and no conflict with his faith in God). Aside from his great love for reading, Andrew was involved in the usual sorts of activities that any other young boy participated in (acting, sports, video games). Through the extensive summer travels abroad with his mother, church summer camps, and philosophy/humanities education in college, Andrew learned how to critically think about truth and man's place in society.

In the interview, Andrew seemed quite relaxed and was comfortable displaying his thought processes as it related to science. He said that public opinions did not affect him and was confident in establishing his own position. Andrew commented on he was much more influenced by what he learned from his teachers in the classroom as knowledge here was grounded in history and tested through the times. It was through the three years of peer discussions involving Aristotle, Socrates, and other philosophers that shaped his logic. When it came to practical applications of the analytical skills he learned in school, Andrew would've preferred a life in poverty as a poet than a role as a scientist who found the cure for cancer. Because his upbringing did not contradict his understanding of scientific progress, Andrew was happy to participate in this study.

The Interview

Facts

Heavily persuaded by Aristotle, Andrew separated his perspective of facts into two categories. (The terms "fact" and "observation" were used interchangeably throughout the interview.) The first category was labeled as **"self-evident" observations (a priori truths)**, an idea that was defined as being devoid of any contradictions or the need for observations/testing. Andrew gave math as an example, discussing how square roots and numbers **have always been true**. "It's just something you know." The second category was known as **"proven" observations (a posteriori truths), which were ideas that could change**. Andrew pointed out how politics and religion were areas where there was room for multiple interpretations. It was likely that people could "create a narrative" based on personal observations, which were tainted with their own specific set of values. **Because proven facts could possibly change, Andrew felt safer when making decisions that involved self-evident facts**.

Laws

Certainty was really important and was evidenced in Andrew's direct statement, "**The laws of science don't change**." Their purpose, he discussed, was to "provide certainty for behavior and the way it is described" and "help people to understand how things *always* act." In a sense, laws were needed as a guide to explain behavioral patterns. Andrew's perspective on education and science was that they needed to work together to bring about a greater understanding for the nature of how things are. He provided the law of gravity as an example, reciting how everything that was not resting on earth was moving towards earth at 9.8 m/s^2 (if it was within the earth's gravitational pull). Andrew placed tremendous value in understanding nature because "the world would be difficult to operate in if you couldn't fully trust anything around you."

If laws were so certain, how were they constructed? Andrew believed **laws were developed from a series of self-evident facts**. Theories, hypotheses, and proven observations *could not be transformed into laws* because these ideas were all based on uncertain principles. If something was uncertain to begin with, it could not be made more certain "because there's still room for doubt." A self-evident fact, on the other hand, "has always been true" and could easily support a law.

Theories

Like much of the public, Andrew **equated theories to "guesses".** He believed that although theories possessed plausibility, one could never fully obtain certainty. "If scientists were so sure about the theory of evolution, then why don't we just call it the *law* of evolution?" Andrew inquired. It was clear that socially constructed meanings of words were critical to Andrew's acceptance of theories. His exposure to what he learned in school, read in the newspapers, and watched on television had always led to a pairing of uncertainty to evolution, which made the term "theory" itself seem like a weak concept.

What does a theory consist of? According to Andrew, theories were made up of hypotheses, self-evident observations, and proven observations. Because proven observations and hypotheses were both concepts that still needed to accumulate additional evidence to gain any kind of certainty, it was no wonder that Andrew doubted the status of a theory. At the same time, though, Andrew did understand that there were certain elements to theories that did not require any kind of testing and were worth accepting (self-evident observations).

Laws enjoy a higher status than theories. This idea was illustrated by Andrew's comment "evolution may not be a law, but it's pretty dang close." What was it, then, that made evolution so close to a law? Andrew understood how important evidence and testing was to the nature of theories, but there was something stopping him from giving evolution the kind of value it would've had if it was labeled instead as a "law". Andrew explained, "There's a lot of proven observations that point to evolution being right, but there are still gaps." Further clarification was provided in the following quotation:

> News sources like *The New York Times* reported findings on different kinds of fossils that have connections to human beings…so in the context the report provides, it makes it seem as if there's still gaps in our understanding of the

> evolutionary process, which holds it in doubt. Additionally, the fact that there are people who claim to be proponents of intelligent design and they are scientists…leads me to believe that evolution is not conclusive. Why would these other people be around? (Andrew, Interview, June 30, 2011)

It was clear that Andrew's stance on the theory of evolution was decided from a rationalistic perspective. He trusted *The New York Times* because of its duration in the U.S. and because of the quality of research into the stories prior to a reporting. Andrew paid attention to the language that was used in the articles and relied on facts (missing links in fossil record) to establish his understanding that evolutionary theory was not yet complete. Even the presence of a group of scientists (albeit they are intelligent design) threatened the credibility of research done by evolutionary biologists. After all, wasn't the nature of science tentative, and wasn't research an on-going process? What was interesting to note, however, was how Andrew used what he knew about the nature of science to dispel certainty of evolutionary theory rather than appreciating scientific progress and the imagination that is required to acquire more information. Given that Andrew had no religious conflicts, opposition to science, and a positive inclination for solving problems, this led me to wonder how the media could transform conceptual thinking among the public. To what extent is this impact, and how long does this influence last?

Evolutionary theory can only be indirectly tested. Andrew did not think it made sense to directly test the "entire theory of evolution" and felt that the best approach in "poking holes at it" would be in evaluating individual observations. Only certain aspects could be tested, and that would have to be done one observation at a time.

According to Andrew, the purpose of science was to test hypotheses – not theories. When asked why, he said, "You never hear about theories becoming laws, but you do hear about hypotheses becoming theories." Andrew's explanation for why theories were indirectly tested seemed to be based on what he pieced together from the media. Could this have affected his perception of the explanatory power of theories?

In an attempt to more thoroughly investigate Andrew's understanding of the nature of theories, he was asked "How certain are we of theories?" A conversation about proving hypotheses rather than disproving hypotheses ensued. Andrew responded to the question, saying:

> I am willing to put my faith in theories, but ones that I believe in. There's an element of faith to theories. For instance, the theory of evolution. We don't have the entire fossil record down…it's still called the theory of evolution because it has not been proven correct or incorrect. **It may be the best explanation we have for a certain phenomenon but it's not rock solid. It hasn't been proven yet**. (Andrew, Interview, June 30, 2011)

Hypotheses

"It's a guess but not in the same sense of a theory." By referring to them both as guesses, Andrew's statement revealed his low level of trust for hypotheses and theories but he was hinting at differences to their nature. While a hypothesis involved both types of observations (self-evident and proven), Andrew stated a theory included both types of observations and a set of hypotheses. Like his earlier assessment with theories, a hypothesis was considered weak because it included proven observations (which were subject to change, allowing room for uncertainty). Of the four major terms (fact, law, theory, hypothesis) discussed in the interview, the hypothesis held the lowest ranking in terms of certainty. In order to illustrate how a hypothesis could increase its confidence level, Andrew provided the following example:

> When I have an observation that is not self-evident, I need to give it the status of fact. Perhaps the observation is that "This glass is half empty" and my hypothesis is "It's half full." I need to prove that it is half full by accumulating other observations (self-evident ones), or I could go off of proven ones, but they must be agreed upon as true by the parties that are evaluating the overall discussion. (Andrew, Interview, June 30, 2011)

Again, Andrew stressed the value behind conversing with others to gain social acceptance of something that would otherwise hold low levels of certainty. In addition to the physical evidence that is used to support a hypothesis, Andrew believed that **peer acceptance is needed before giving much weight to a hypothesis**. (This is in contrast to Shawn, who believed the data alone was used to verify a hypothesis.)

Table 3: Andrew's Visual

Utility in building certainty **(1 = most; 5 = least)**		**Description of Certainty** **(1 = most; 5 = least)**	
1. Self-evident observations		1. Law	
2. Proven observations	Facts	2. Self-evident observations	
3. Hypothesis		3. Proven observations	Facts
4. Theory		4. Theory	
5. Law		5. Hypothesis	

Summary

Andrew, a philosophy student, viewed the natural world and observed truth through the lens of Aristotle. Because the ancient philosopher saw knowledge as a priori and a posteriori, Andrew imitated his teacher's categories by creating his own: self-evident facts and proven facts. One could feel most assured of self-evident facts because they did not require any testing and would thus gain acceptance from people of all cultures. Proven facts, on the other hand, was something Andrew felt less certain about. Only after multiple testings and verifications could one gain confidence in the data. Relating theory to a "guess", Andrew believed that theories were slightly more certain than hypotheses and very "close to a law". A theory, however, could never become a law. By its definition, theories hold some level of uncertainty because they included observations that had still yet to be proven. Laws, on the other hand, were believed to be composed of self-evident observations (which did not need proving) and thus convinced Andrew that laws were the most trustworthy statements one could make about nature.

Andrew relied on a mixture of sources to confirm what he knew about truth and evidence evaluation strategies. His experience as a philosophy student led him to appreciate reading physical texts and to participate in many seminar discussions with other individuals who actively spent their time critically thinking and reflecting on historical narratives. Even though he may not have had similar experiences as a practicing scientist, Andrew was able to demonstrate his understanding of the nature of theories because he appreciated different kinds of evidence. Andrew, who was less familiar with direct manipulation of lab materials, relied more on what was written or reported by eyewitnesses. Based on an assessment of these sources, Andrew concluded that evolution could not be tested directly due to the awareness of many hypotheses available for evolution.

<u>May, "The Social Justice Activist Educator"</u>

Background

May, the oldest in a family of ten, grew up on a farm along the border of El Paso. Despite her large family size, May said she was still able to attend a parochial school (no conflict with evolution) up to the 6^{th} grade and then later switched to a public school. She recalled the economic challenges that most students in her school faced and admitted that her family was in a more fortunate position. May's upbringing was centered around her family's barbeque business, where she took charge of the finances, filled orders and packaged food for all of their customers. When she found out she was admitted to UT – Austin for graduate school (curriculum and instruction department), May was ecstatic at the opportunities that would come her way. Prior to graduate school, she had some social justice education experience at another college institution. She had always been interested in education and sought ways to improve the plight of underprivileged groups.

As busy as she was with her new role, May enthusiastically volunteered as a participant for this study. May informed me that even though she had never taken a formal evolution course, she enjoyed talking about science as it related to multicultural education. The core principles found in both topics helped her to improve her skills at evaluating and differentiating pieces of evidence. She referred to Kevin Kushamiro's work being a large influence on the way that she thought about how this could be done. After graduating with her PhD, May planned on becoming a college education professor and working to reduce the gap between marginalized communities (mainly for Spanish-speakers). Her purpose in knowing how to examine evidence was to combat oppression.

Although her focus was on racial issues, she was also interested in studying issues related to gender and sexual identity. Because May spent a lot of her time learning about "the foundation for the differences and the implications for the lived realities" of these people, she felt she was well-read across many disciplines (history, science, math, and education).

The Interview

Facts

Facts are more "fluid than people allow them to be". Instead of prescribing to a definition that described facts as being immutable, May perceived facts to be "different for different people" due to separate worldviews. What kinds of things shaped May's worldview? The following excerpt provides some good insight:

> I think with my background in diversity and social justice…a fact… I can connect that to science and the way it's used to oppress marginalized communities, or like uh…[for] some people it's a big movement where there are only 2 biological sexes right? That's a fact. Well, that's not necessarily a fact because there's a whole intersexed community. Two percent of babies are born as intersex…the biology only allows for 2 sexes but the reality is not true… (May, Interview, June, 13, 2011)

May's primary concern was how facts were used to bring separation between different groups of people. She believed that people judged based on a rigid interpretation of facts. This judging led to the oppression of other people who appeared to be different. As a result of this, **the way May defined, analyzed, and used facts was intimately tied with a desire to assist marginalized groups**. She went on to enumerate more diversity issues:

> You can look at you know…lesbian gay bisexual identity…that used to be considered a disability…this was in the ADA handbook…anything in there is considered a fact and it's used to oppress…but we're still living in that history as if it's a fact even though we know that it's not a disability anymore, right? We can look at identity; we can look at race; we can look at sexuality; we can look at *any* of these things and find the way that science and facts have had an impact on the marginalization…so as a social justice educator and understanding that link between science and history and oppression…is really important. (May, June 13, 2011)

May attributed her approach in examining facts to an in-depth exploration of literature involving both scientific and historical elements. Research into one field was always informed by the other field, giving May a deeper understanding of the nature of facts (how they came to be, who developed them, their predicted value, how they were used). **While science produced the facts, a look into history provided meaning and reasons for those facts**.

Consequently, this led to a discussion on the purpose and nature of science. May inquired if the **goal of science was to "disprove facts and have other facts build on facts**". She expressed sympathy for the many people who understood facts as ideas that never changed, stating "this kind of goes against what science is. Isn't science about analyzing established facts?" In addition to fulfilling her own personal goals as a social activist, May's other reason for why facts needed to be fluid in nature was because of the **potential that she saw for societal growth**:

> If facts seem so concrete and kids don't even want to challenge it, then we've limited something different…to develop a challenge to the fact…for them to think of ways to disprove it…that should be an option. I think that's a way we can create a space to create different ways of thinking about things. (May, June 13, 2011)

Theories

"Framework to guide research and allows for an understanding of facts." May saw a theory as something that would start her on the pathway to acquiring more knowledge. A theory, then, was a very broad and general idea that could be expanded or attached to other theories. This general idea would guide the question, which would in turn guide an even more specific question (the hypothesis) and would then propel her into research. It is here that facts were made more clear. Instead of deflating theories to just a guess, May understood the complexity of theories and saw their **potential to explain facts**.

In providing cultural relevant theory as an example to illustrate her thoughts, May revealed that she also believed that theories could help social justice educators to **discover new facts**. Theories were now useful in explaining facts that already existed, but also in finding information that the researcher was not aware of. The cultural relevant theory was something that would aid the researcher in understanding oppression in a "more factual way". The strength of a theory was dependent on the research that followed.

Theories do change for different situations. While most people feared the uncertainty of theories, May believed that it was important to acknowledge the **tentative nature of theories** because "if theories have too much power, then this would limit the **possibility for exploration or creativity or reflection**." Change was necessary because it enabled scientists to be people of imagination. Interestingly, May's philosophy on change did not arise from a strong science background or much experience in a lab setting. Her vision for how she would operate in the world came from a personal desire to alleviate the conditions for those who lived in an oppressed community. To do so successfully, then, May learned to "always challenge what is normal." May's goals as a social activist (while immersing herself in interdisciplinary research) helped her to establish a unique position to understand theories and to appreciate their utility.

Laws

According to May, laws were "more scientific based" and didn't really fit into her frame of thinking. This was another way of saying that she was unsure about how to define laws or how to use them. She then discussed how laws were usually associated with an equation and thus, belonged in science and math. It was apparent that May was not comfortable with laws because she did not hear about them often in her area of work.

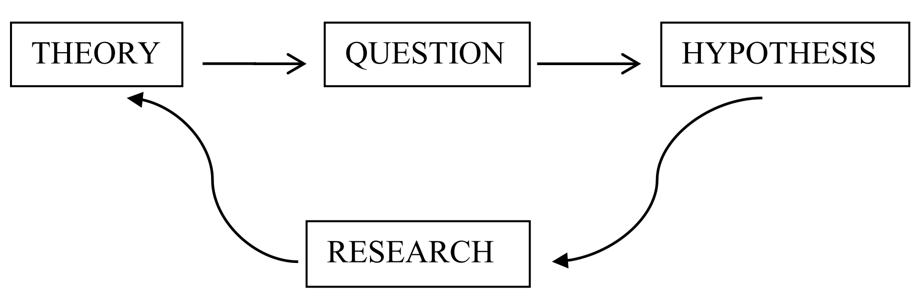
After some thinking and perhaps feeling pressured to say something, May guessed that laws were "kind of like a scientific theory" in that it gave her a framework and guided her for more research. Laws, however, had a "**more practical connection and usage than theories**". May projected this belief onto what she assumed to be the thinking that belonged to most people. She also expressed concern for the boundaries that students would create for themselves as a result of laws being "**more serious" than facts**. It seemed that although May's personal belief was that laws were highly regarded in terms of certainty, *she did not value them as useful for societal progress if they were too definite*. Again, May stressed the value of creativity and exploration. She did not want people to be trapped with how they interpreted facts or laws, and preferred to side with the tentative nature of all things.

Hypotheses

"An educated guess," May replied immediately. Hypotheses were used often in May's area of study and she seemed much more comfortable discussing this topic than she did when we had talked about laws. Because a hypothesis was a **very specific question**, it was the final step before diving into the research component. While May understood that hypotheses were formulated by observations, she believed those observations to be unbiased. She provided a simple explanation, saying, "Observations are just what I see. One, two, three."

Unlike the other participants, May did not compare hypotheses to theories as these ideas were clearly distinct in her mind. Theories were very general and "started" the process of thinking; hypotheses came along later and were very specific questions that led directly to research. In May's worldview, theories were not "hypotheses nestled within hypotheses" (as Shawn indicated). Neither did she view hypotheses and theories as concepts that had competing levels of certainty (as Andrew indicated).

Figure 1: May's Visual



Summary

May, a social justice activist educator, saw the world as a place that was too certain of facts. Facts could be developed by theories or just simply exist. May expressed a heightened feeling towards theories and saw much value in them. The function of theories was to guide research and to make facts more clear. Theories were the first step and led the researcher to think of a question, which was followed by a more specific question (hypothesis). At this point, research could then begin which would reveal a deeper understanding of facts or the discovery of new ones.

Because of the seriousness people took with established facts, May feared there would be specific groups of people (Latin Americans, lesbian, gay, bisexual, and transgender groups) who would be further oppressed than they already were. Facts, May believed, were in actuality more fluid in nature. To demonstrate her point, she cited the constant revisions in science and history books. The ability for facts to change was good for new growth and societal developments. In the same vein, May ardently spoke of her desire to challenge facts and explore concepts in "much more dynamic ways". Facts could not change, she believed, without the theories to guide the research.

Brandon, "The Business Consultant"

Background

Brandon grew up in one of the largest cities in Texas and attended public schools. He recalled not appreciating what he learned in science as he felt it was not relevant to his life. It wasn't until college that he started to take an interest in the subject (although he only took 1 science course), recognizing that what he was learning was much more applicable to his daily life than he had previously thought. Brandon wasn't sure what he wanted to major in, but because his parents urged him to go into either engineering or business, he eventually chose the latter. Besides attending the required courses, Brandon enjoyed being with his friends, playing and watching basketball, going to parties, watching television and even began experimenting with drugs and alcohol. Brandon expressed appreciation for all of these college experiences and their consequences, as this is what he attributed to shaping his mind and the way he saw the world. Unlike the previous years, Brandon was now confident with his own thinking and learned that he did not need to rely on friends. Instead, he could use newspapers and online sources to confirm or to discover information.

During the interview, Brandon was very easy-going, joked several times, and laughed at himself. He was eager to share his ideas and was intrigued by the nature of the questions since he rarely had conversations like this with his friends. At the time, Brandon had just quit his business consulting job of two years and was seeking an MBA in financing. He said he was tired of working with local Austin musicians/artists and needed to find something more stable.

The Interview

Facts

Facts were very certain. These were statements that Brandon claimed to "**have zero margin of error, or as close to zero margin of error as possible**." Because facts were already established as a scientific validity, there was **no need to question** or test them any further. The only way that facts could change is "if we change our definition of facts" but otherwise, facts did not have exceptions. Brandon believed that the instrinsic value of facts was the certainty that it provided. Interestingly, though, he did not think we should "rely on facts all the time" as this would **stump progress**.

Brandon was adamant with his definition for facts despite his comment that "**facts don't change – just what we discover changes**." So new discovery does not lead to new facts? Brandon clarified what he meant by providing an example of how people used to think the earth was flat (a theory), and compared it to how we view the earth now as being elliptical (a fact). According to Brandon, facts stay the same but the way we think about those facts may differ. When he was prompted to think about time as a factor, Brandon quickly changed his mind and noted:

> Based on scientific evidence that is accessible for now…uh, granted that we're disproving a lot of theories as time goes on…but based on that premise…if time was infinite and if we get to keep researching things, then I guess on that premise, nothing's ever a fact. (Brandon, Interview, June 15, 2011)

If time was infinite, then facts would have the possibility of changing. As the exchange on facts evolved, it became clear that Brandon was afraid of being incorrect and felt that he needed to define things as he had always heard them in the classroom. He was not ready to create his own definition although he was comfortable using the term the way he wanted.

Because of the level of seriousness that Brandon gave to facts, he took extra precautions before confirming facts as true especially due to his experience with business and advertising. Facts were more willingly accepted after personal encounters with them. Brandon expressed the need to analyze the data himself so that he could see if the results had been replicated several times "given certain circumstances". He understood the nature of experimentation and the need to hold variables constant before establishing something as factual.

Theories

Theories were less certain than facts. Brandon revealed his disbelief in theories, describing them as statements that were "*trying* to use scientific evidence to support it". He understood theories were yet to be proven and **still needed multiple testing** before assessing the scientific validity. If the results were similar, Brandon agreed that theories could then be promoted to facts. He used the entanglement theory as an example of "something that they're still trying to figure out" and how "there's still not been enough experiments to suggest that it's still true". It was obvious that Brandon valued multiple testings before confirming the authenticity of a theory. What was unclear, however, was whether or not Brandon believed that theories could explain existing facts.

If theories still required additional testing, then why did Brandon conclude that **theories were more valuable than facts**? He argued:

> I would say what's more valuable to society or mankind, or however you want to phrase that, is a theory because it **challenges what we think we know and it could lead to a new fact**. Because once you prove something, you know it's there – that's great. But if you just rely on facts all the time, we would never progress. (Brandon, Interview, June 15, 2011)

Laws

Brandon thought about two types of laws: legal and scientific. He distinguished them in the following excerpt:

> Laws of science are based on scientific observation and not politics or any other man-made function. Legal law is man-made in the sense that we can change the law if we want to. If there's a general consensus among the people to change a law, then we can. But you can't change Ohm's law just [because] you want to. You can't change the law of gravity if you want to. (Brandon, Interview, June 15, 2011)

Because scientific laws were based on scientific observations of nature, they were more reliable than legal laws. Brandon elaborated on this point and discussed how scientific laws were more associated with facts (something he characterized as having a high degree of certainty). When asked to clarify, Brandon said that laws were the "premise for proven facts". Were there two types of facts now (proven as well as unproven)? Assuming earlier that all facts were proven in Brandon's mind, I proceeded to ask him to be even more detailed in his explanation.

There was some confusion between theories and laws. Initially, Brandon thought of theories as his 'unproven facts' while laws acted as his 'proven facts'. Laws, then, would be more certain than theories. As the conversation evolved, though, Brandon dismissed these ideas. As he pondered about examples to demonstrate what he meant, Brandon concluded that "scientific laws are no different from scientific theories". The two terms were now interchangeable in his mind. If the two terms were meant to be the same, why would there be two distinct words for them? Brandon replied:

> It's **just a way of organizing things**, I believe… like a way of organizing one's thoughts… cause I think it would be a correct statement to say 'Ohm's law is a

> theory'… technically, I think Ohm's law might be an equation. The concept that it tries to express is a theory. (Brandon, Interview, June 15, 2011)

Unsatisfied with his own response, Brandon attempted to explain his thinking in another way:

> **Scientific law is used to describe a pattern found in nature**, I guess, that's repeatable through experiments. A **theory is something anyone can come up with**. That doesn't mean the theory isn't true or that there isn't any validity to it. A theory is something that someone comes up with. A law is something already naturally existing but then we just put a label on it. (Brandon, Interview, June 15, 2011)

Because a **law** was something we could find in nature, Brandon believed that it was **directly testable**. A **theory**, on the other hand, was a projection made by a person and thus could be **either directly or indirectly testable**. When asked which of the concepts would hold more weight for him, Brandon sided with laws because they were things that we could observe. This explains why the theory of evolution did not seem very factual to Brandon since he was the kind of person who appreciated physical evidence before assigning trust to an idea. It is important to note that Brandon only provided direct evidence for the theory of evolution.

Hypotheses

"An educated guess," Brandon said blankly. He did not mind providing the popular definition for the term and waited a while before continuing. While a "hypothesis is just a simple question", a "theory is the premise a scientist uses to try to prove something." It seemed that Brandon believed theories were filled with purpose and more intentional than hypotheses. He went on to describe how multiple hypotheses were needed in order to "discover what the truth about the theory is." Brandon believed **hypotheses and theories had mutual benefits** to one another; one did not have more value than the other (even though his visual showed otherwise).

Table 4: Brandon's Visual

Level of *Certainty*: (1= most, 3=least)	Level of *Importance*: (1=most, 4=least)
1. Fact	1. Theory
2. Theory/law	2. Hypothesis
3. Hypothesis	3. Law
-------------------	4. Fact

*Note: Levels of certainty did not correlate to levels of importance.

Summary

Brandon, a business consultant and finance graduate student, drew two visuals to represent his understanding of the terms (hypothesis, theory, law, and fact). The first visual represented his personal level of certainty with the terms. He rated facts highly because this was information that he knew already had a sturdy foundation. They no longer needed to be verified. Theories and laws were both placed directly below facts. Because Brandon perceived both terms to be less certain than facts, he supported their interchangeable usage. Hypotheses were easily ranked last since Brandon was aware of the fewer tests that are associated with these types of questions.

The second visual, which depicted levels of importance, helped to clarify some of his fluctuating points and his intended meanings for the terms. For example, Brandon said he saw no difference with how theories and laws were talked about in scientific discussions. However, Brandon placed different values on each term (in his visual) which implies that he understood the distinctive nature of theories and laws; he was just unsure of how to use them appropriately.

In discussing how one would set up levels of importance for the terms, Brandon interpreted importance to mean how one would depict a sequential picture of the scientific process. Theories were immediately listed first because of their ability to "challenge what you know" thus giving them more fact-finding value. Even though Brandon had the least amount of confidence for hypotheses, he sought to use them next in the line-up in order to "lead your theory in the right direction". This would then allow for the scientist to "quantify a law" that would represent one's original theory. Once a mathematical law was created to explain patterns found in nature, Brandon thought it was possible to further understand the "truth that is already there" or to discover new facts.

Cross-Analysis Summary

Facts

Unlike Brandon who used his business sense to claim "facts were facts", all of the other participants understood the tentative nature of science would permit facts to change. While Shawn and Andrew acknowledged the fluidity of facts due to their acceptance of uncertainty, May eagerly discussed how the spirit of being open to change would benefit people and give them opportunities to explore. Could majoring in science, philosophy, or education lead one to a more dynamic approach to looking at and evaluating information?

Many students believe that "evolution is speculative and can only be supported by hard scientific facts" (Lord & Marino, 1993). What seemed to set Brandon apart from the other three participants is how similar his response was to the average high school biology student. The idea that facts are immutable pieces of information is based on a pre-mature understanding of science; how evidence is constructed and assessed against new data. Could this be an indication of how Brandon's business professors discussed facts in the classroom? What were some factors that might have kept them thinking of facts in this way? What was the role of facts in developing new strategies or in solving problems? How would this look different if facts were not as rigid as one thought?

How Theories Relate to Facts

Since there was nothing novel about facts, this actually prodded Brandon to search for other types of ideas encompassing opportunities for research. Theories, then, possessed the most value for the business consultant because they acted as a "launching point" and helped him to assess or discover facts. The motivation to invent and create was a lesson Brandon was well aware of from his own field of study. Similarly, May echoed her support of the need for imagination and exploration in science, which is a basic tenet of the nature of science (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). She referred to theories as her framework, guiding her to research which would allow her to more deeply probe at facts. Brandon and May highly valued theories, though, not because of their ability to explain facts or predict future occurrences, but because of the possibility of retrieving facts at the end of the experiment. Like much of the public, these participants believed that scientists were only interested in collecting facts and thus held misleading ideas that facts were the hallmark of science (Wolpert, 1992).

Shawn, on the other hand, chose to use theories to explain current observations but did not attempt to find any more certainty. He resisted mentioning whether theories could be promoted to facts, or if they explained the relationship between facts. Shawn's concrete sentiment towards this matter was expressed when he said, "We often accept things as 'facts' but then later to find out that in reality they are not true or correct." Shawn's acceptance of "tentativeness and uncertainty is a characteristic of all science" (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002).

Andrew took a different approach. He discussed the inductive role of facts prior to theory development. Of the four participants, Andrew was the only person that directly mentioned how essential it was for scientists to use facts in the process of establishing theories. Because Aristotle was ingrained into his mind, though, Andrew defined facts differently from the others. His facts were broken into those that were self-evident and those that had still yet to be proven, which explained why Andrew was not convinced that theories could reach a higher status of certainty. Andrew believed that it was in the very *nature* of theories that would never allow for it to achieve a definite state of confidence, whereas Shawn believed that life in general could never be too certain.

How Laws Relate to Facts

The most diverse responses were discovered between ways of reasoning about laws and facts. One did not have to be an expert to have been exposed to the terms; they are used in daily life between friends, student and teacher, newscasters, blog members, etc. Since the terms are widely applicable to many areas of study, they are likely to have evolved in meaning. Personal biases and experiences contribute to the ongoing transitions of the terms, requiring people to define before dialoguing many times. To have any meaningful conversation on a specific topic, it is necessary to be familiar with other perspectives. As such, the divergence in meanings for the participants in this study was expected.

A major difficulty with establishing accepted nature of science meanings is trying to deduce the literature contributions by scientists, science educators, and philosophers of science. They disagree across and even within specialties (Alters, 1997) much like the participants within this study. Thinking of the components (self-evident facts) that made up a law, Andrew saw laws as very certain. May, on the other hand, did not think of how laws were constructed. Instead, she compared laws and facts as if they were two discrete objects. Even though she emphasized that nothing should ever be considered definite, May wondered if laws were more serious than facts. This suggests an understanding that facts are promoted to laws. On the contrary, Brandon maintained a stable position on facts throughout the interview and asserted their authority over laws. His need for certainty was greater than his appreciation for the tentativeness of science. Because Shawn already painted the world as an uncertain place, neither facts nor laws existed in the scientist's mind. It was due to the constant discovery of exceptions that Shawn boldly suggested we remove the terms facts or laws when discussing science. According to Scott (2004), though, there were many historical implications with using these terms as scientific explanations. Each term held an entirely different meaning and made communication easier between scientists. Furthermore, she pointed out the value of assigning degrees of importance to facts and laws rather than eliminating them completely from scientific discussion. Disagreements between experts make nature of science conversations increasingly difficult and leads to a greater feeling of uncertainty for science. This situation presents a serious question: How does a scientist who values uncertainty garner support from an average layperson who resists the very idea of uncertainty?

How Laws Relate to Theories

Brandon and Shawn both agreed that the terms were uncertain. While Brandon's reasoning was based on his belief that laws and theories had yet to be proven, Shawn's reality with his work as a researcher told him that things could always be disproven. Even though they used the terms interchangeably, it was for clearly opposing reasons. For the business consultant, it was the number of experiments that helped to validate one's conclusions; for the scientist, it was an acceptance of the tentative nature of science in general.

Contrary to what has been presented in the literature about students' views on theories being promoted to laws (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), Shawn and Brandon preferred to give theories the golden status (even though they believed them to be uncertain). Shawn chose to dismiss the term ‘law’ and to examine the world using theories because this would more appropriately fulfill his scientific worldview of uncertainty. Brandon, who valued creativity and imagination, simply saw theories as the starting point for experimentation.

The other participants provided even more varied answers. May admitted that she was not familiar with laws in her field of education research. She guessed that laws and theories could be used similarly, guiding the researcher in the quest for facts. Andrew, however, believed that laws and theories were distinctly unique. In this philosopher’s mind, laws attained the highest level of certainty because they contained only self-evident facts (or direct observations). Theories were not yet proven. The way that these terms have been generally characterized by the continued vernacular use of the terms (ex. evolution is just a theory) has led many students to believe that theories require additional testing before attaining any kind of scientific validity (Alters & Nelson, 2002).

Even though Andrew refused to grant theories a higher status, he understood the nature of experimentation for theories. Theories were indirectly tested and even with increasing evidence, would not be promoted to a law. This was in contrast to what Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) observed to be the weakness of most students. He understood theories and laws to be separate ways of knowledge, and that one could not transition into the other. Andrew’s perception of the theory of evolution, then, did not come from a poor science background or strong religious practices, but from a rational philosophical (or scientific) perspective for how the components of theories could provoke additional questions. Andrew used what he knew about logic and questioning to try to make sense of the controversial topic. Holding fragments of uncertainty for theories, then, does not imply a weak understanding of the nature of theories but a commitment to the very nature of science. Additional data on philosophy students could provide more insight as to how consistent this is across the discipline.

How Theories Relate to Hypotheses

When discussing the scientific process, the participants provided an assortment of answers. According to Andrew and Shawn, the main focus in an experiment was on generating hypotheses. Multiple tests resulting in similar answers then gave way to a theory (Alters & Nelson, 2002). For Shawn, though, a “theory” was another way of saying “hypothesis”. Because of this, each of these concepts had equal opportunities of being disproven. Shawn’s openness to doubt came from his realization that mistakes were an innate strength to the scientific method. There was always going to be another explanation. Unlike Shawn, Andrew saw it possible to live in a world that was filled with the certain and uncertain. Initially, Andrew seemed to trust theories more than hypotheses due to his recognition and explanation of how evidence contributed to each. However, he persistently used the term “guess” in exchange for both concepts, which suggests that Andrew’s understanding of the nature of the terms was highly influenced by his social and cultural milieu. The same was reported by authors in a few other studies (Aikenhead & Jegede, 1999; Deniz, Donnelly, & Yilmaz’s, 2008). What one sees or hears in the media can influence scientific reasoning, but the degree to which it does this is still unclear.

Ironically, May and Brandon (non-scientists) stressed the importance of theories and ordered them first in the scientific process and then hypotheses later. They frequently attributed the power of a theory to its fact-finding ability, and highlighted the need for creativity and imagination in science. It was in defining how hypotheses were used in an experiment that the two participants diverged in their logical thinking (or perhaps only in the way they individually expressed themselves). For May, hypotheses were very specific questions that one developed after a theory was chosen. For Brandon, the purpose of hypotheses was to "lead theories in the right direction." Because the end result of hypotheses for each participant was to better understand or discover facts, it can be assumed that their thinking was not significantly different.

Individual Perspectives on Evolution

Shawn, "The Science Guy"

Shawn highly accepted the theory of evolution. The strength of his acceptance of evolution came from his ability to delineate other theories of evolution. Natural selection was just one mechanism and does not explain all evolutionary events (Catley, 2005; Miller, 1999). The theory of evolution is supported by much evidence, but not much more certainty than a hypothesis. While others may have pointed out uncertainty as a legitimate reason to reject evolution, Shawn had already accepted uncertainty as a natural part of any science experiment; all that mattered to Shawn was the weight of the evidence, which is what gave him confidence in the theory itself. Like participants in Lord and Marino's study (1993), though, Shawn misunderstood the nature of evidence to be only things that one could see directly and observe.

Andrew, "The Philosopher"

Andrew accepted the theory of evolution, but to a lesser degree than Shawn. Andrew understood that the strength of the theory of evolution came from a multitude of sources but was not able to list out all of the theories of evolution (due to his lack of science content). Aside from direct evidence, Andrew also valued historical and circumstantial evidence in supporting the theory because he understood that evolution could only be indirectly tested (which was surprisingly not mentioned by Shawn). He thought that component parts of evolution had to be individually tested, an understanding supported by Mahner and Bunge (1997). This was in contrast to participants from Dagher and BouJaoude's study (2005). Because they only understood direct testing in science, they did not value historical evidence as much as physical evidence. Unlike those participants, Andrew did not feel the need to subject historical evidence to tests that were designed for direct evidence. This reflected an appropriate understanding of the nature of evidences and how they were related to one another.

Andrew's degree of acceptance, though, was limited by a number of reasons. Andrew perceived the evidence provided by evolution and intelligent design as possessing similar levels of weight, which was comparable to the beliefs held by students in Hokayem and BouJaoude's (2008) study. He questioned why these intelligent design scientists would exist if the data presented by evolutionists was sufficient. He also questioned the certainty of evolution because of the connotation that 'theory' had as a guess. It was clear that social influences were constantly competing with what he had been able to correctly rationalize for himself. This study differed from Hokayem and BouJaoude's study, however, on how participants viewed the missing links in the fossil record. While Andrew recognized there were gaps, he did not use this information to prevent him from accepting the theory of evolution; legitimately, it just gave him questions to consider. In the end, Andrew relied on his firm understanding of how theories were based on many hypotheses that have not yet been disproven, thereby giving him strength and certainty to the theory of evolution.

Brandon, "The Business Consultant"

Brandon accepted the theory of evolution (also to a lesser degree than Shawn). His focus on the amount of tests and evidence explains why he accepted the "theory of evolution over the theory of creationism". His use of the term 'theory' for both positions does not imply a non-distinction between the nature of evidences found for each; rather, he was using the term as a simple way to say 'explanation'. In contrast to the participants in Hokayem and BouJaoude's (2008) study, Brandon understood the nature of evidence for evolution was more scientific and thus, not comparable to creationism. "Scientific evidence only suggests the way evolution works itself – not what got evolution there, or why evolution happens."

Although he seemed to understand the purpose of evidence, he failed to understand the nature of experimentation and scientific thinking. Like the other students noted in Alters and Nelson's (2002) study, Brandon thought the theory of evolution was still insufficient and required more testing before it could become more factual. This is a reflection of Brandon's misunderstanding of the nature of theories in their ability to "explain facts and laws" (Scott, 2004, p. 14). So why did Brandon accept the theory of evolution? He referred often to the amount of evidence and reasoned if the explanation "sounds like it makes sense", then the explanation was acceptable. This poses a serious question: Does this suggest that individuals can accept evolution without really understanding the nature of experimentation and scientific thinking?

May, "The Social Justice Activist Educator"

May accepted the theory of evolution, but it was unclear what the degree of acceptance was as most of her examples about theories were not specific to evolution. May held the perspective that theories were particularly useful ideas that allowed humans to understand scientific facts. Unlike the participants in Dagher and BouJaoude's study (2005), May appreciated historical evidence in addition to physical evidence. This allowed her to see the meaning behind the data. Because of May's immense appreciation for theories as a framework for additional research, she did not think it was appropriate to say that evolution was "just a theory". Theories, for May, were powerful avenues that allowed the researcher to create, imagine, and freely explore a more specific question.

Although May claimed the theory of evolution was supported by an overwhelming body of empirical evidence, her understanding of the nature of that evidence was unclear. Was this evidence direct or indirect? Instead of elaborating on how evidence was assessed or validated, she spent the majority of the time discussing how evidence was used for a specific purpose and stressed the importance of allowing for evidence to change. She was constantly wondering "Which ideas can be challenged?" which implied that while she supported the theory of evolution, nothing was ever too certain.

CHAPTER 5

CONCLUSIONS

This chapter includes a discussion of findings, implications, limitations of the study, recommendations for future research, and pedagogical applications. The research questions that will be addressed are as follows:

1. Can interview methodologies be used to give a credible and informative account of how 4 interviewees use theories, facts, laws, and hypotheses?
2. How do students' interpretation of these terms frame attitudes and accounts of evolution as it is used in biology?

Discussion

There were many intriguing aspects to the findings in this study regarding how students' interpretation of NOS terms can structure their views on evolution. Two points warrant discussion and further empirical investigation.

The first point to address is how the specific use of interviews exposed a variety of participant thoughts on questions related to the nature of science as it relates to basic science terminology (fact, theory, law, and hypothesis). Although some agreement was found for the terms "fact" and "hypothesis", one participant was critically dependent on facts for all of his decisions while another participant desired to eliminate the term completely from his vocabulary. All participants understood "hypotheses" had the least amount of scientific weight as an explanation for observable phenomenon, but two participants who emphasized the need for creativity and exploration believed experiments started with “theories.” The degree to which participants were certain about these concepts and its related sociocultural influences, whether a hierarchy was visualized with these terms, and the need for imagination to engage in experiments varied across respondents. The use of interviews was helpful in extracting detailed information from each individual to allow for more meaningful comparisons of scientific ideas.

The confusion of how to use “theories” and “laws” among scientists, philosophers of science, and educators has been cited widely in the literature for more than a few decades (Alters & Nelson, 2002; Cartwright, 1983; Elgin, 2003; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Ruse, 1988; Sober, 1993). Because there is disagreement among professionals within the same field of study, it was expected that participants would also disagree here. Interestingly, the varying ways that participants interpreted and used the term “theory” still led them to an appreciation for the theory of evolution. Had a close-ended attitude assessment been used, we would not have seen much difference in understandings of the nature of theories between individuals especially if they had all selected the “correct” answer. Individuals are unique in their perspectives and it is important to reflect on those differences as future students could hold similar conceptions.

The second point revealed in the data is how a participant’s emphasis on evidence for acceptance of evolution does not necessarily correspond to an understanding of the *nature* of scientific evidence. Participants accepted evolutionary theory because it was the best explanation available for biological life, implying they all recognized that the theory was more than just a personal belief. It was interesting, though, how each participant thought about evidence. When probed further, I found a wide range of perspectives on which types of evidence would count for evolution, how evidence is evaluated, and how competing scientific explanations are compared. Similar to college participants in previous studies (Dagher & BouJaoude, 2005; Lord & Marino, 1993), three out of four participants gave direct evidence for the theory of evolution while only Andrew (the philosopher) emphasized the importance of circumstantial and historical evidence in establishing the theory. He demonstrated his understanding of evolution as a phenomenon that was very broad and the need to test several hypotheses in order to support evolution. In harmony with this study, Johnson and Peebles (1987), Scharmann (1990), Scharmann and Harris (1991), and Sinatra, Southerland, McConaughy, and Demastes (2003) have demonstrated empirical evidence depicting a sophisticated understanding of the nature of science and how it is related to acceptance of evolution. Interestingly, Shawn was able to exhibit his degree of evolution acceptance because of his awareness of a set of theories supporting evolution rather than an understanding of the nature of evidence (indirect) that is needed to support evolution. Brandon and May also relied on tangible evidence, but came to accept evolution because of their general interest in theories as predictors for new information.

What has been discovered in these findings is how very different individuals who think and use basic science terminology in different ways can examine the same topic and still find common ground. We believe this is due to a shared appreciation of theories in general and a reflective approach to the scientific process. The participants each came to accept evolution as a result of valuing evidence and being able to compare evolution to rival theories. In Lawson and Weser's (1990) study, the researchers showed a positive relationship between reflective reasoning skills and commitment to evolution. All individuals in this study also showed an acceptance of the tentative nature of science as a strength to research rather than using this as a reason to reject evolution.

Implications

A closer look at how scientific language is used by the participants across the disciplines of science, philosophy, education, and business indicates much confusion in understanding basic terminology. This is alarming considering sophisticated ideas are built on one's ability to communicate basic ideas. The situation becomes increasingly complicated when the terminology (fact, theory, law, hypothesis) is regularly used in mainstream media and social conversations as was indicated by a few participants. The evolution of meanings and interpretations creates a small disparity between individuals within the same field, and an even larger disparity between individuals from different fields of study. Such differences are noticeable when living in community with others. An efficiently running society, then, depends on members who can speak the same language to find common ground and strategize for future growth. Thus, the communication gap surrounding scientific terminology is in much need of our attention.

Agreeing on common meanings for basic nature of science terminology has many ramifications. First, it *situates* a person's mind and teaches him/her how others would approach the question. Second, it *reduces* misinterpretations of scholarly documents and allows a researcher to make fewer mistakes. Third, it *saves* time and money for the politician, educator, scientist, clergyman and entrepreneur. Fourth, it *encourages* newscasters and journalists to accurately record stories. Fifth, it can *prevent* society from making unethical decisions by ensuring that all citizens are fully cognizant of the issues involved. Whether the terms are used for science or another matter, they are considered basic enough to be used across many areas of interest; this makes a uniform understanding of the terms more essential, especially for such a rapidly growing society.

I was interested in nature of science terminology as it relates to evolution because of the potential impact the information would have on a long-standing resistance to learning evolution. In contrast to what has been presented in the literature, the data here show that a uniform meaning on the term "theory" among these four participants was not essential to accepting evolution. There is a presumption among many researchers (Lederman, Wade, & Bell, 1998; Ryan & Aikenhead, 1992) that a dissonance between accepted definitions and student-constructed definitions for terms used in NOS would result in deleterious results for science education. Two students (Andrew and Brandon), who expressed a lower level of certainty for evolution, credited this to the negative connotation of the term "theory" (Alters & Nelson, 2002) but still accepted evolution as a better explanation than intelligent design or creationism. The participants showed that there was something more powerful influencing their perceptions of evolution than simply understanding how the scientist would use "theory". From this, I can conclude that a shared interpretation of how to use these terms across students will make little difference in a favorable disposition towards evolution especially if students already have positive ideas about science and practice reflective reasoning in assessing evidence.

The use of interviews, then, was significantly helpful in determining student biases and their interrelated sociocultural factors, allowing me to draw out how these kinds of things in combination with key components students desired to reveal about the scientific process had swayed their position on evolution. Allowing the student to communicate openly and paying attention to what he/she had to say has been potentially more informative than any survey or questionnaire in precisely determining where the science educator can focus to improve attitudes towards evolution.

Limitations of the Study

Limitations are potential confounding factors in all studies. The possible limitations identified for this study are:

1. Case studies cannot be generalized to larger populations.

One of the most common criticisms for case studies is its inability to be generalized to larger populations (Stake, 2000) in education research. It is impossible to control for all variables when interacting with human subjects. We can determine, however, how specific individuals respond and more thoroughly characterize their influences in a case study situation. Such information can then be generalized to predict either future occurrences or different situations with that same case study. Although the information in this study cannot be generalizable with all cases that fall under similar conditions (field of study, religious upbringing, age, 2-parent household, evolution exposure in high school), patterns can be more clearly identified with increasing research in this area.

When interpreting a case study, science educators tend to bring their own assumptions and experiences into the study, which can lead them to their own naturalistic generalizations (Stake, 1995). Readers can take this information and draw new information from it, or even confirm what he/she already knows.

2. Case studies are time-consuming.

While in-depth discussions require more time than a multiple choice test, they also provide more than a snapshot of individual thought processes. The detail from the data can offer valuable insight to science educators, informing them of what, how, and why the individuals reason the way they do about certain issues. This information can then be used as a guide for future teaching and provide direction for specific improvements in the curriculum.

3. Case studies are subject to researcher biases.

Researcher biases cannot be completely eliminated but they can be minimized. In this study, trustworthiness was established through member checking during and after the interview, peer debriefing, and triangulation of resources (field notes, participant drawing, audiotape transcripts). Every attempt to reveal researcher biases was revealed in the introduction so that the reader could understand what specifically interested the researcher and thus the direction of the study.

Future Research

To see if there a pattern for scientific reasoning that can be found across individuals within the same field of study, research should be extended to include additional participants enrolled in the fields of: science, philosophy, education, and business. The fields were chosen to examine a diverse group of individuals who have been trained to reason about very different kinds of problems. How is critical thinking and basic vocabulary used across groups? Is it possible for people across groups to communicate clearly with one another and make similar decisions? Additional data on individuals within shared fields of study may also provide insight into areas of interest, biases, and goals for groups of individuals studying the same thing.

Given the timeframe of this particular study, we were only able to investigate how one's interpretation of nature of science terminology affected attitudes towards evolution. In the future, we would be interested in examining how one's interpretation of such terms would relate to *understanding* of evolution. How a student weighs evidence and compares ideas as a result of such interpretations may have a larger impact on content that is actually learned than on *attitudes* towards a controversial topic. This would help science educators to more seriously consider the implications of the data provided.

The broad overlying question for the future study should be: Is an understanding of nature of science related to an understanding of evolution? Other questions to consider are: What key differences between students matter in the development of scientific reasoning? Is there a way to measure the impact of sociocultural or media influences on students? What specific factors (epistemological beliefs) affect feelings of certainty for the student? Is one's degree of certainty related to acceptance of ideas? Can the relationship be applied to controversial topics like evolution?

Pedagogical Applications

> *If we are to be successful in teaching evolution, we must take into account our students' worldviews as well as their individual understandings and misconceptions. It is important to know our students, their cultures, personal histories, cognitive abilities, religious beliefs,* [and] *scientific misconceptions.* [It is also important] *to address directly the likely cultural/religious concerns with evolution and to do so early on so as to break down the barriers that keep many students from hearing what you say.* (Smith, 1994, p. 591)

Several researchers (Cobern & Aikenhead, 1998; Hokayem & BouJaoude, 2008; Johnson & Peebles, 1987) have advocated establishing a bridge between scientific knowledge and the student's cultural milieu. Similar to these earlier findings, this study shows the significance of *paying attention to student's values and beliefs* as they play a heightened role in the construction of scientific knowledge, and especially for issues as delicate as evolution. Such knowledge can be properly shaped in the classroom if the educator seeks to implement routines that have an intentional purpose. An effective strategy for checking a student's pre-conceived notions is to encourage small group peer discussions (Scharmann, 1994). Because learning often occurs in social environments, it is vital for instructors to structure time for this in the classroom. How the information is taught will be more important than how much content is offered in teaching evolution. As students discuss evolution during these more intimate encounters with other students, they are forced to re-examine the adequacy of their own ideas and can often times use the opportunity to acquire more scientifically sound concepts (Alters & Nelson, 2002). Allowing for students to argue about their ideas can promote content learning and the exercising of reflective and critical thinking skills that are necessary proponents to more complex concepts.

For a successful student-led group discussion (see Nelson, 1994 for elaboration), the instructor should *ask students to be prepared* prior to their engagement by having them each complete an assignment before class. At the start of the discussion, the instructor should *present focus questions* that will guide the group in thinking about a problem that possesses some level of difficulty, prompting students to work together to solve it. Generally, this will illuminate both conceptions and misconceptions of students as their thinking will be made visible. Through these social interchanges, students would be more willing to exchange ideas with one another and to listen to alternative views if there is a *respectful environment* set in place. It is important for the instructor to make the expectations and goals of these peer discussions clear so that all members can be productive in the learning process. By implementing peer discussions as a part of the routine of the science classroom, students gradually become more comfortable with sharing and considering alternative points of view thus reconstructing their own knowledge and enjoying science more in general.

Understanding students' epistemologies and how they construct their knowledge can be tremendously helpful in improving attitudes towards evolution as this creates a path for educators to appropriately guide students. The educator should demonstrate respect to students and a level of sensitivity for alternative issues that are brought up. Instead of viewing matters of faith as impediments to the learning of evolution, the educator should view student conceptions as important aspects of scientific practice and engage them in meaningful ways (Rudolph & Stewart, 1998). Providing students with homework assignments such as a short intelligent design reading paired with a student-led analysis of the text during the next class day may be more beneficial than controversial. The educator is in actuality encouraging students to compare the validity of ideas and to actively engage in scientific thinking. This act of deference to the students is very powerful because it serves to *humanize* a topic that many are hesitant to discuss out of fear or lack of knowledge, which can then more assuredly motivate students to explore evolution content in a deeper way. A positive attitude towards learning evolution, then, can be achieved by the educator who respects his/her students and demonstrates this through integrating evolution content with students' pre-conceived notions.

In teaching evolution effectively, the instructor must think carefully not only about the kind of classroom environment he/she is promoting but also how the entire individual was developed. How does this student reason? What ways of reasoning are meaningful to the individual? There is no prescribed way to teach evolution but there is a responsibility to pay close attention to individual ideas as this provides the educator researcher with valuable insight into helping students to form well-reasoned arguments for their views on evolution.

***Appendix A: Interview Protocol**

Introduction to Interview: "We are interested in how you understand some ideas related to scientific reasoning and evolution. In particular terms like hypothesis, fact, theory and law are often used to express our ideas about science and evolution. This interview is structured around exploring a sense of what these terms, or related concepts, mean to you and how they are related to each other in your understanding of evolution. The questions in this protocol and any follow-up questions we may ask are meant only to help us clarify aspects of your understanding. Although we intend focus on particular terms, you should feel free to modify the questions, add observations or raise issues about whether these terms are relevant to how you view scientific reasoning and evolution."

Ask participant to describe what he/she understands about the following through examples given.

1. Theories in relation to facts?

2. Theories in relation to laws?

3. Theories in relation to hypotheses?

4. How certain are theories? Could they change for different situations?

5. Do you think the word "theory" in a lab setting is used similarly in our everyday language? What could this potentially mean for the other words mentioned above?

6. Different perspectives tend to lead us to different ways of looking at things. Would understanding the way scientists use these words help you to see the theory of evolution in a different way?

Note: As part of clarifying the responses given to these prompts, the interviewee will be asked to compare terms relative to importance to scientific reasoning or to explain an ordering in time that the terms would be relevant.

*Appendix B: Sample Interview Transcript with the "The Science Guy"

Interviewee: How certain are we of theories?

Sam: I mean, some things are probably more rigorous than others but I think that's one of the reasons why in the sciences you don't find people out there testing and developing theories in the sense of the definition people would use in public, or in high school, or in middle school where you're kind of learning the scientific method. You might have a theory for something and you're calling it that because it's a collection of these different hypotheses that you're interested in…some bigger topic…and that's probably some definition we've talked about today or in some textbook or you know my theory for this is xyz…

Interviewee: If I were to interview someone else from a different specialty within biology, do you think they'd have a different perspective of how to use "theory"? Does the definition change for different situations? Or can that be a one term that can be applied to all and still garner the same amount of confidence?

Sam: I'm not sure. You'd certainly get a different kind of perspective cuz as I said before the term "theory" is not one that is used as frequently.

Interviewee: And neither is "law" as you said before.

Sam: Yeah. My guess is you might end up with a textbook definition of it or how they would use it in their own personal interactions with professors or other grad students.

Interviewee: And I think for you, you said that even though it's not used very often for you, you would prefer to use the term "theory" more often to describe things rather than "facts"? You said "everything's kind of a theory."

Sam: Well I think that acknowledging the uncertainty of things is important and I think that understanding what makes something science…what makes something a scientific endeavor is important and the method about the scientific method is important…but you know, I almost feel that the debate about what a "theory" is and the appropriate use of the "theory" is beyond the scope of science…and its more of a philosophical discussion about truth and certainty.

Interviewee: Do you feel it's appropriate to bring up these philosophical conversations or should it be segregated into an English class or humanities?

Sam: Well uh…

Interviewee: Do you think this is something that college professors ought to incorporate into their own classroom to reform attitudes about evolution?

Sam: I think it depends...I think my opinion is that people should have an understanding of the material before...I would be reluctant to have a conversation with someone about what a "theory" is if they couldn't give me a "hypothesis". I'm not saying "Sit down and give me a definition of what a 'hypothesis' is but tell me a 'hypothesis' about something…one where you can go out and gather some evidence for and falsify". If you can do that, then you understand something about the scientific method…and something about evidence…and critical thinking…and that is more important than being able to have a high level discussion on a "theory", and whether… in my opinion, when someone says that something's a "theory", we've already left the realm of science.

Sample Interview Transcript with "The Social Justice Educator"

Interviewee: Earlier you said it was important to use language as a tool…a very powerful tool in order to help someone understand something. I guess my broader question is "Do you think if you were to train someone who is not a scientist to think and use the words the way a scientist would, they could then have a better understanding of the theory of evolution?

Mary: Maybe. Well even though language is a way to understand, it's not the only way. My mother who may never understand some of the language I use because she didn't go to college. Our thinking, though, is very parallel because we have similar worldviews. I'm very much about youth empowerment. I would be like, "Go into your community and go explore on the internet. Find a question you're interested in and then bring this back to class. Then go through the whole process with them. Then define a theory and say here's why…having them explore through their own experience right…through their own knowledge base…they're all a good way to engage them and to bring science in…but it all starts from their own space.

Interviewee: Um hmm. So while defining terms is important, it's not the only way…but to be done in combination with helping them to think on their own?

Mary: Helping them to connect to where they're at, or where they're from…you know what I'm saying. What I feel what we are doing in education is really disconnected from the reality. I can learn all these theories or definition, but I don't understand how to interconnect all these subjects or these realities. How is it connected to history, or math, or English? We don't get that because we're isolated…we need to explore these things in a much more dynamic way. I can transfer some of the words I use in my space because I can see how they are intersected, how are subjects so interconnected. So helping them to explore this in a more fluid dynamic way can help them to see these things.

Interviewee: So how do you think we'd go about doing this especially when you see the separate classrooms?

Mary: I don't think the system is built for that; it's built for these sallow things. We can work on critical thinking.

Interviewee: How do you think teachers in your hometown work on critical thinking abilities?

Mary: It's a hard question…but I think they are lessening critical thinking skills rather than heightening them due to the TAKs tests...regurgitating information. It doesn't take any critical thinking skills so…and the passion for learning. We just make people learn these facts. But we should say "Think of a question and go explore". I could care less if a student could define a law but if they know how to think about it, they'd have more passion. That's what's important to me. I start them thinking of themselves and where they're from…what is your identity…how does this shape you…3 sessions later let's define these words we keep on using…and then they go through that process.

Interviewee: So you think defining should be happening along the way or at the end…

Mary: I don't think there's one pedagogical tool for this…if it's happening organically, then let's bring it up. I think we tend to develop curriculum in a step 1, step 2, let's move forward way….well, no youth is step 1, step 2…they're more step 1, step 8, step 5…we need to be more organic. We need to use our intuition to guide us where to go.

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