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Teachers' Orientations Towards and Awareness of Students' Evolutionary and Natural Selection Conceptions and Their Influence on Teaching Practice

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Teachers' Orientations Towards and Awareness of Students' Evolutionary and Natural Selection Conceptions and Their Influence on Teaching Practice

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Dedication

This work is dedicated to my parents, Rodolfo and Josefina Lucero—two glorious people whose collective mission was to educate their children. Their drive and work ethic was the most valuable lesson they could have imparted to their sons and daughters. I will be forever thankful to them for molding and shaping the person I am today.

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Teachers' Orientations Towards and Awareness of Students' Evolutionary and Natural Selection Conceptions and Their Influence on Teaching Practice

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Evolution is the conceptual framework on which biology is based, but its components are not well understood by many individuals, and the topic is home to many deeply-held alternative conceptions. Nevertheless, eliciting alternative conceptions can be a valuable resource for both teaching and learning, but teachers often feel ill-equipped with how to elicit their students' alternative conceptions and/or use them in an effective manner to deepen their students' understanding of scientific concepts.

Little research exists regarding how the daily demands and practices of a group of high school teachers from the same campus impact their students' understanding of evolutionary concepts when being aware of, eliciting, and potentially using their students' alternative conceptions as resources for learning. Using a conceptual framework that focuses on the relationship between teachers' subject matter knowledge (SMK) and aspects of pedagogical content knowledge (PCK), this set of studies reports a line of inquiry from a single site that researched how: 1) students from an urban high school learned various evolutionary and nature of science (NOS) concepts; 2) one group of biology teachers went about eliciting and using their students' alternative conceptions on various evolutionary concepts during classroom instruction; and 3) another group of biology teachers planned and implemented an instructional unit on evolution when their students' alternative conceptions were predicted and identified with a concept inventory, specifically the Conceptual Inventory of Natural Selection (CINS). Various data sources, including classroom observations and teacher interviews, were used to examine the teachers' practices in the latter two studies.

Results from the third (current) study revealed the teachers were well aware of their students' natural selection alternative conceptions and this area of their PCK was not necessarily related to their SMK of the topic. Sustaining a kind of supportive learning environment where alternative conceptions were elicited and used for learning was a goal of the teachers, but they felt they could not capitalize on such opportunities for learning due to various personal and/or institutional constraints. Results also demonstrated that the teachers valued how the CINS probed student understanding and used its results strategically, and made several recommendations for high school use.

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Chapter One: Introduction

Evolution is the common thread that runs throughout all of biology. Evolution and its key mechanism of natural selection provide the foundational framework for how biology is organized and should be taught (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 2012). On the surface, the core ideas of natural selection appear to be straightforward and are based on three basic claims: 1) All organisms tend to produce more offspring than can survive; 2) there is variation among organisms within a population; and 3) this variation is passed down to future generations through inheritance (Gould, 1996). Natural selection is the main process that is responsible for the complexity and diversity of the living world. Without it, the natural world would be stagnant.

Evolutionary Core Concepts

Natural selection is certainly part of evolution's greater whole and Mayr (1982, p. 479-480) proposed that evolution could be stated as a group of five facts and three inferences:

> Fact 1: All populations have the potential to grow at an exponential rate.
> Fact 2: Most populations reach a certain size, and then remain fairly stable over time.
> Fact 3: Natural resources are limited.
> <u>Inference 1:</u> Not all offspring survive to reproductive age in part because of competition for natural resources.
> Fact 4: Individuals in a population are not identical, but vary in many characteristics.
> Fact 5: Many of the characteristics are inherited.
> <u>Inference 2:</u> Survival is not random. Those individuals with characteristics that provide them with some advantage over others in that particular environmental situation will survive to reproduce, others will not.
> <u>Inference 3:</u> Populations change over time as the frequency of advantageous

alleles increases. These could accumulate over time to result in speciation.

In 2005, the Biological Sciences Curriculum Study (BSCS) continued with the above summary's line of thought and presented more simplified claims as being appropriate content for beginning or high school instruction on evolution. These claims were: 1) species evolve or change across time; 2) species evolve from common ancestors; 3) new species form from existing species (speciation); 4) evolution usually occurs gradually; and 5) natural selection is the most important mechanism by which adaptive evolution occurs. (pp. 36-37)

Other authors (Ohlsson & Bee, 1992; Andersson & Wallin, 2006; Catley, 2006; Passmore & Stewart, 2002; Shtulman, 2006; McVaugh, Birchfield, Lucero, & Petrosino, 2011) have proposed and compiled slightly different concepts that are also appropriate for beginning instruction. These concepts include: 1) heritability of phenotypic variation in individuals; 2) randomness; 3) origin and role of intraspecies variation in individuals; 4) accumulation of changes over many generations (adaptation) in a population; 5) competition for limited resources by individuals; 6) differential survival rates of individuals (based on biological fitness); 7) differential reproductive rates of individuals; 8) changes in the distribution of individuals with certain heritable traits within a population; 9) distribution of species and biogeography; 10) speciation and macroevolution (to include deep time); and 11) extinction. In addition, Catley and Novick (2009) proposed seven evolution-related events that a "scientifically literate" population need to appreciate and know and these events were: 1) the age of the Earth; 2) the age of the first fossils; 3) the appearance of the first eukaryotic cells; 4) the Cambrian "explosion"; 5) the appearance of the first mammals; 6) the extinction of most dinosaurs; and 7) the appearance of the first "Hominid"—*Homo habilis*. The authors claimed that knowing these events and further studying deep time is absolutely essential to understanding evolution. In their perspective, this knowledge will lead to very important insights, which are that: “1) over periods of time very improbable events do occur; and 2) very small, seemingly insignificant change do accumulate, often with major impacts” (p. 330). More research is needed to assess which of the concepts listed above are more difficult to teach and understand than others, but in one survey (Rutledge & Warden, 2000) secondary science teachers had difficulty understanding items related to environmental change, reproductive success, the evolutionary process, and the role of genetic variability.

Importance of Natural Selection

Natural selection’s core ideas have a direct significance to human health and well-being, such as understanding the environmental impacts of overhunting and overfishing by humans (Darimont et al., 2009; Jørgensen et al., 2007) and the evolution of antibiotic and pesticide resistance (Palumbi, 2001). Therefore, it is logical to expect that an understanding of the natural selection process should be made a priority and is of utmost importance. Unfortunately, over thirty years of research confirms the fact that natural selection is poorly understood. Not only is natural selection misunderstood by the general public, high school students (Demastes, Good, & Peebles, 1995), and college undergraduates (Bishop & Anderson, 1990), but it is also frequently misunderstood by those one would not expect—those with postsecondary instruction in biology--including biology majors (Dagher & BouJaoude, 1997), medical students (Brumby, 1984), and science teachers (Nehm & Schonfeld, 2007).

The perception that natural selection concepts are so easily understood is unfortunately reinforced by many scientists. To professional biologists, “…natural selection is so logically compelling that its implications become self-evident once the basic principles have been conveyed" (Gregory, 2009, p. 156). These "basic principles" are regarded as concepts which are easily comprehended. However, the reality shows a stark contrast. As noted by Bishop and Anderson (1990), "the concepts of evolution by natural selection are far more difficult for students to grasp than most biologists imagine" (p. 425).

Evolution Makes Sense, But Is Difficult to Understand and Grasp

Previous psychological research has revealed that individuals exhibit a naïve psychology that uses powerful, intuitive approaches in the absence of other knowledge when trying to make sense of understanding the world (Evans, 2008; Lombrozo, Shtulman, & Weisberg, 2006; Sinatra, Brem, & Evans, 2008). These approaches are "default" modes of thinking and can constrain how new explanations are formed, especially in evolution (Evans, 2008). Evans (2008) argues that these "hard-wirings" in the human brain are actually more significant barriers to understanding evolution than the much more widely studied nature of science (NOS) misunderstandings.

One of the major reasons why these "hard-wirings" are so difficult to modify is because individuals do not often see them as misunderstandings (Sinatra et al., 2008). To compound the problem, evolution is an abstract process whose explanations do not lend themselves easily to everyday ways of thinking (Smith, 2010). The default approaches humans possess are workable in many circumstances and effective in daily life, but they can lead to deeply held alternative ways of thinking about evolution and natural selection because certain explanations are innately more attractive than the best scientific explanations.

As mentioned previously, evolution through natural selection is logical and has tremendous power in application in that it effectively explains how organisms “fit” to their environments (Gregory, 2009). However, understanding and grasping its mechanics and implications is more challenging than is initially assumed. Figure 1 displays just some of the areas that have been previously identified as having an impact on the understanding of evolution. A cursory examination of each of these areas reveals how alternative conceptions can arise and stay surprisingly stable, despite instructional efforts (Jensen & Finley, 1996; Ferrari & Chi, 1998; Nehm & Reilly, 2007; Spindler & Doherty, 2009).

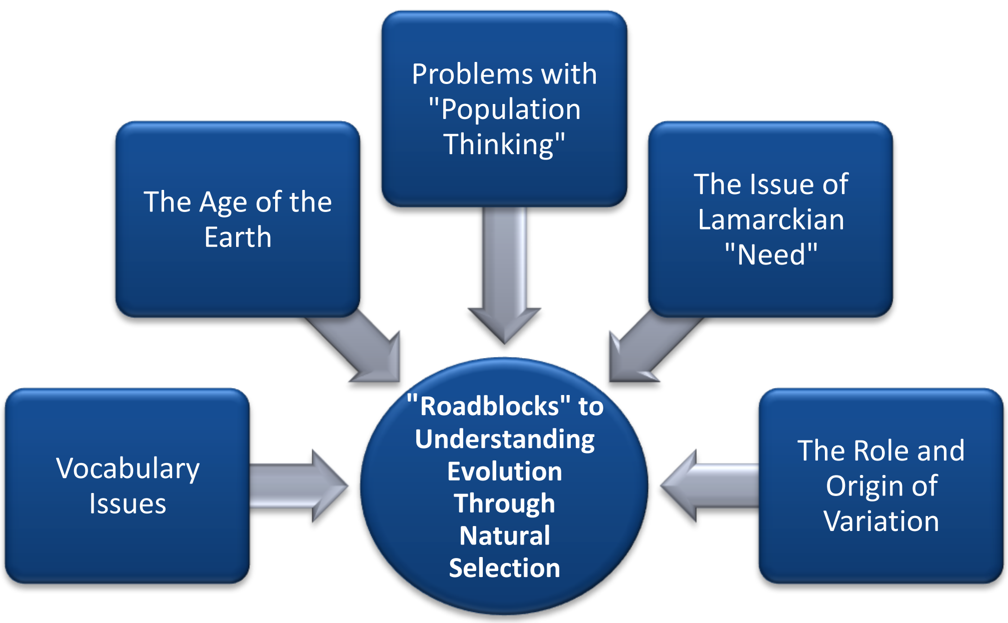


Figure 1: Selected factors causing difficulty in understanding evolution.

Like many topics in biology, evolution has its own set of vocabulary terms and concepts, such as *adaptation, variation, fitness, inheritance, mutation,* and *“survival of* *the fittest".* Many times, these terms get confused with their "everyday" interpretations. For example, when individuals think of *fitness,* they often translate its meaning to physical strength, stamina, or wellness (Alters & Nelson, 2002). However, in a biological sense, *fitness* refers to the ability to produce viable offspring. Also, non-authoritative sources' (e.g., television, movies, popular magazines, family members) interpretation of evolutionary mechanisms and terms are related to the area of vocabulary difficulties. For example, many individuals have a sensationalized and pop culture vision of what *mutations* are. Instead of viewing mutations as relatively subtle changes in DNA sequences that can occur among members of a population, individuals will tend to imagine "X-Men" from the popular comic book series and movies or those mutations that result in horrible or grotesque physical features (Bixler, 2007).

Next, conceptual difficulties can arise from thinking evolution through natural selection takes place within a relatively short time frame (e.g., Cotner, Brooks, & Moore, 2010). Many individuals do not realize the Earth's age is approximately 4.6 billion years old; therefore, they expect to witness evolutionary changes of higher taxa within their lifetimes. Simply stated, many individuals possess an insecure *deep time* cognitive framework and fail to fully grasp certain geologic events, such as mass extinctions and the appearance of different life forms (Trend, 2000). Much of this poor understanding of deep time has been attributed to an overemphasis on *microevolution* within the biology curriculum (Catley, 2006; Catley & Novick, 2009). Microevolution, in contrast to the more deep time-centered *macroevolution,* describes changes in genetic allele frequencies that occur over time in a population. While both processes are correct, microevolution can occur over several generations in lower taxa, whereas macroevolution takes place over thousands of years.

Certain conceptual difficulties can arise from thinking evolution is a process that occurs in single, solitary individuals, as opposed to entire populations (Alters & Nelson, 2002; Bishop & Anderson, 1990). In fact, no organisms change as a population adapts (Gregory, 2009). The proportion of traits that change occurs across many generations as some traits are passed on at a higher rate than others, and the "direction" in which the changes occur is dependent on the environment. Environmental changes can make previously beneficial traits neutral or detrimental and vice versa. This difficulty may involve implicitly viewing evolution as a "direct" process instead of an "emergent" process, which involves seeing the interactions among all the individuals in a population as total effects or "the collective interactive outcomes of all the constituent components" (Chi, 2005, p. 174). Chi and colleagues (Ferrari & Chi, 1998; Slotta & Chi, 2006) claim that many of the difficulties students have with understanding evolution are due to "ontological mistakes", that is thinking of evolution as a direct process instead of an emergent one or as a "thing" as opposed to a process in general. According to these authors, teaching evolution requires an ontological shift in thinking, where students learn the differences between direct and emergent processes and then apply this knowledge to understanding natural selection.

The individual vs. population way of thinking may also be due to intuitively thinking individual organisms change their traits because they "need" to change them. This Lamarckian view posits that individual organisms change over their lifetimes to become better able to survive and pass these changes on to their offspring. In turn, entire species will then "transform" as a response to need (Alters, 2005; Shtulman, 2006). Needs-based explanations are very common in evolutionary instruction, and appear to be “one of the strongest and most commonly observed default approaches in individual naïve psychology” (Smith, 2010, p. 547).

Another innate tendency related to Lamarckian thinking is to assume variation within a population arises in response to need (usually an environmental challenge) and that any new variation is always beneficial. In fact, variation arises in an undirected fashion by random mutation. Some mutations are detrimental, some neutral, and some are beneficial to a population. While difficulties with understanding how variation arises are an issue with evolutionary instruction, failing to recognize that variation plays an integral part in evolution is a deeper concern (Gregory, 2009). This naïve interpretation of evolution is rooted in “essentialist” thinking, in which species are thought of as exhibiting a common “essence”, and any variants among the population are largely unimportant deviations from the essence. This tendency to “essentialize” arises early in childhood and tends to remain a default position for most individuals (Stevens, 2000; Gelman, 2004; Evans, Mull, Poling, & Szymanowski, 2005; Shtulman, 2006).

The catalog of natural selection misconceptions is extensive and unmistakable, ranging from the use of teleology (e.g., Pedersen & Hallden, 1992; Tamir & Zohar, 1991; Sinatra et al., 2008) and anthropomorphism (e.g., Kampourakis & Zogza, 2008; Sinatra et al., 2008) to conceiving of change in organisms as being due to use or disuse of organs (e.g., Settlage, 1994; Demastes et al., 1995; Ferrari & Chi, 1998; Kampourakis & Zogza, 2008). As individuals charged with communicating natural selection concepts to students, teachers are advised to become familiar with and elicit their students’ common misconceptions within their classrooms. However, it is increasingly apparent that teachers, particularly those in the secondary ranks, are not familiar with these natural selection conceptions and fail to recognize them among their students (Lucero & Petrosino, 2012).

Research has sought to understand why evolution through natural selection is conceptually difficult for teachers to teach and students to understand. Researchers have historically looked to science classrooms for insight and intervention within this area. Many studies have been aimed at creating and implementing effective evolutionary instruction to restructure such conceptions of students, and while some interventions have been successful, most efforts have not achieved substantial understanding among students (Smith, 2010). Inadequate implementation is often cited as a main cause for little to no effects of such interventions. Many of these intervention studies are admirable in their design, but some fail to take into account how their implementation is affected by teaching practice and teacher knowledge. As a result, teachers do not seem quite ready to embrace such reforms (DeBoer, 2000). Indeed, among the factors that affect classroom instruction are: 1) teachers' own understandings and perceptions of evolution, and 2) concerns over how evolution instruction will be perceived by students, parents, and administrators (Asghar, Wiles, & Alters, 2007; Moore, 2007). Furthermore, teachers differ in the amount of time they spend teaching evolutionary concepts, the attitudes they project during such instruction, and whether evolution is presented as a unifying theme (Brem, Ranney, & Schindel, 2003).

Rationale for Research Inquiry

As mentioned above, lack of teacher content-specific understanding is one of the factors that impacts this instruction (Asghar et al., 2007), but other factors related to teacher knowledge affect instruction as well. Whether these factors include knowledge and beliefs about the learning of evolution and science in general to knowledge of learners (including their prior knowledge and alternative conceptions), these factors are not often closely examined within the context of the classroom. That is, surveys, questionnaires, and other quantitative instruments provide a general idea that teacher understanding and evolution beliefs are factors that affect evolution instruction, but a rich descriptive examination of what having this understanding and knowledge (or lack thereof) looks like from a classroom perspective has yet to be fully articulated.

The set of three studies described here are all part of a research agenda that seeks to obtain a more holistic picture of the state of teaching and learning evolution within a typical high school setting. For many of the reasons described above, these research studies critically examined some of the factors that were playing a role in how evolution was taught, with particular attention paid to: a) students' ideas on evolution; b) teachers' understanding and beliefs of evolutionary theory; and c) teachers' knowledge of their students' ideas with respect to evolution. In particular, the remaining chapters detail how information learned from two previous pilot studies led to the shaping and formulation of ideas for the current study, which sought to answer the following research questions:

RQ1: Does a group of biology teachers' self-professed orientations to science teaching and evolution align with lesson implementation?

RQ2: Aided by the use of a conceptual inventory, what is the nature of the teachers' *knowledge of their students' alternative conceptions* with regards to natural selection (Anderson, Fisher, & Norman, 2002), specifically? How does the teachers' elicitation of students' evolutionary alternative conceptions inform their teaching practices?

RQ3: Does the teachers' *subject matter knowledge,* with respect to natural selection, relate to the knowledge of their students' alternative conceptions? How does the teachers' SMK manifest itself when students reveal their alternative conceptions during classroom instruction?

RQ4: How do teachers view the concept inventory's utility as a classroom tool for gauging student understanding of natural selection?

RQ5: As measured by the concept inventory, do the teachers' respective students maintain or modify their alternative conceptions regarding natural selection?

Having rich classroom descriptions, such as this set of studies, can potentially reveal valuable insights about how teachers' subject matter knowledge may be related to their pedagogical content knowledge. In addition, very few research studies relay information about how teachers, both collectively and individually, think of and plan instruction on evolution and how their students' ideas influence their instructional decisions. The set of rich descriptions described here can potentially inform how science educators, content experts, and professional development coordinators should approach pre- and in-service teacher evolutionary understanding and preparation by providing real world examples of the issues teachers encounter when teaching evolution in its entirety.

Chapter Two: Literature Review

This chapter begins with a discussion of the salient points that have direct bearing on the set of studies that are described. The first major construct that is discussed is *alternative conceptions*. Within this discussion, some background and context of alternative conceptions is provided, along with how they can be viewed as resources for learning. Methods for eliciting alternative conceptions are also described, with particular attention being paid to *concept inventories'* development and use in different domains of science. The next hierarchical construct that is discussed is *pedagogical content knowledge*, its associated relationships with other areas of teacher knowledge, and how it provides explanatory power to viewing student ideas. Lastly, a discussion of specific pedagogical issues surrounding the topic of evolution and an accompanying synthesis of how the chapter's important points apply to this line of research inquiry follow.

Theoretical Framework

Following the constructivist tradition, all knowledge is individually and socially constructed and based on a learner's preexisting knowledge and experiences (Ausubel, 1961; Driver, 1983, 1989; Smith, diSessa, & Roschelle, 1993), but this preexisting knowledge may be at odds with the accepted curriculum knowledge (Driver, Squires, Rushworth, & Wood-Robinson, 1994). Indeed, eliciting students' alternative conceptions is seen "as the essential first step in the process of teacher-facilitated conceptual change" (Morrison & Lederman, 2003, p. 850). By using students' alternative conceptions as one of its constructs, this research study acknowledges the importance of recognizing students' preexisting knowledge and experiences when facilitating instruction.

Background on alternative conceptions. The fact that students do not arrive into classrooms as blank slates was truly brought forth by Jean Piaget, and by the late 1970s science educational researchers began to take notice as to what students were saying and doing on a number of intellectual tasks. They reported students often had ideas that competed with formal scientific explanations and these ideas were quite resistant to change (Clement, 1983, 1987). These ideas were coined as *misconceptions* and seen as impediments to learning formal scientific ideas. The prevalence of misconceptions in different fields began to be exposed and any shift away from misconceptions to knowledge of expert concepts must have involved some sort of replacement through accommodation (the reconstruction of mental schema to better account for perceived phenomena), assimilation (building on existing mental schema) (Piaget, 1983), and reorganization (establishing connections between previously independent networks of knowledge) (Piaget, 1983; Hiebert & Lefevre, 1986). That is, "learning involve[d] both the acquisition of expert concepts and the dispelling of misconceptions" (Smith et al., 1993, p. 122). According to Smith et al., implicit in this replacement view was the assumption that removing misconceptions had no negative consequences because they had no productive role in the building of expertise knowledge.

However, it became increasingly apparent that the replacement view needed to be rethought for two main reasons. First, replacing one flawed conception for the correct one is not a simple one-for-one exchange. These concepts are not necessarily separate, independent units (diSessa, 1994). Learning is a complex process and various studies have shown that students shift between flawed and correct approaches during the same problem-solving situations (Clement, 1987). Second, the replacement view is somewhat at odds with constructivist ideas that state learning involves the process of adapting prior knowledge (Elby, 2000). This framework then becomes concerned solely with providing "right" answers (Willingham, 2009). With the replacement view or assimilation of ideas into mental schemas, misconceptions take on a mistaken identity and need to be "overcome"; therefore, this prior knowledge does not serve as a resource during the acquisition of new concepts (Smith et al, 1993).

The term *alternative conception* was coined during the early years of misconceptions research (Resnick, 1983; Hewson & Hewson, 1984) and is viewed as a more appropriate term for the purposes of this research study because it can be seen as a different framework for thinking about the ideas that students bring with them to science classrooms. With a topic as complex as evolution, replacing novice concepts with formal scientific ones oversimplifies the learning process. Alternative conceptions are exactly what their name implies: alternative ideas for how the world works. They may be faulty, but then again, they may not. Nevertheless, they may be useful in building expert understanding.

Alternative conceptions as resources. Rather than viewing alternative conceptions as problematic and unproductive, the research presented here adopts the view that these ideas can be useful in different contexts, especially when other novice ideas are involved (Elby, 2000; Smith et al., 1993). These novice ideas may also be flawed, but they may be refined and developed for mature understanding (diSessa, 1994). Given appropriate instruction, these novice ideas may be productive in the learning process. Science teacher learning about the role and value of student ideas may be described as a learning progression which has upper and lower anchors with multiple pathways between them that are possible (Duncan & Hmelo-Silver, 2009; NRC, 2007). The lower anchor could represent an acceptance that students' ideas play a role in learning and the upper anchor may be considered a more sophisticated view of student ideas as the raw material of learning, with successful elicitation and incorporation being integral parts of a teacher's practice. When considered as a whole, this progression-approach to viewing student ideas represents an important shift in how teachers think, especially when one enters the teaching profession with a conception that science knowledge is transferable from one individual to another.

If used as resources, alternative conceptions can foster further growth and development of ideas and ultimately lead to meaningful understanding of scientific concepts (Elby, 2000; diSessa, 1994; Scott, Asoko, & Leach, 2007; Larkin, 2012). Alternative conceptions that are elicited and used for learning are closely tied to different formative assessment efforts of scientific concepts (Black & Wiliam, 1998a, 1998b), but these efforts may also access personal, environmental, and social resources as well (Cohen, Raudenbush, & Ball, 2003), which then may bring about a metacognitive awareness in students about their alternative ideas (Larkin, 2012). In this sense, students receive opportunities to compare their alternative frameworks with other ideas when they offer explanations, make arguments, and provide justifications (Beeth & Hewson, 1999; Hennessey, 2003; Duckworth, 2006).

Awareness of students' alternative conceptions. However, despite science teachers realizing the importance of student ideas and their alternative frameworks, they remain unaware or unsure of how to incorporate them into instruction (Gomez-Zwiep, 2008; Davis, Petish, & Smithey, 2006; Meyer, 2004; Morrison & Lederman, 2003; Otero & Nathan, 2008). In spite of having heard about the idea of student [alternative] conceptions, one-third of 30 elementary teachers across seven different districts in California were unable to give one example of a student alternative conception from their own experiences, even after examples were provided (Gomez-Zwiep, 2008). In their study of four experienced secondary science teachers, Morrison & Lederman (2003) found that even though the teacher participants believed it was important to learn what students already knew prior to instruction, they rarely used any formal assessment tools to probe for student understanding and most student preconceptions were left unexplored by the end of instruction. In some cases the teachers tended to view the presence of alternative conceptions after instruction as an indicator that reteaching was necessary and correct or accurate information needed to be transmitted to students (Davis et al., 2006). In a similar vein, Otero and Nathan (2008) found teachers who either: 1) did not respond to student thinking; 2) responded only to academic ideas; or 3) responded to their students' prior experience-based (which may form an alternative framework) and academic ideas but did not link the two. The researchers concluded that pre-service teacher education has an essential role to play in preparing teachers to elicit and use student ideas.

In researching novice secondary science teachers' practices, Windschitl, Thompson, and Braaten (2011) tracked changes in teachers' views on the role of student ideas in planning instruction. As part of their project, Windschitl et al. developed various categories (e.g., "working with students' ideas") for measuring the extent teachers used student ideas in their practices. A three-level rubric for "working with students' ideas" evaluated the teachers' use of student ideas in their practices. The first level they identified was labeled *monitoring, checking, reteaching ideas.* At this level, Windschitl et al. indicated that the teachers began instruction without knowledge of student ideas and focused their instruction on ensuring that correct information was delivered to students. Checks for understanding took the form of whole-class discussions and teachers engaged in individual tutoring to confirm that students learned what was covered during various lessons. The next level identified was *eliciting students' initial understandings.* Even though the teachers at this level elicited students' ideas through the use of student questions, conceptual frameworks, or hypotheses about scientific phenomena, they did not consciously use this information about their students to shape their subsequent instruction. The most sophisticated of the three levels was termed *references students' ideas and adapts instruction.* At this level, teachers elicited their students' ideas about science and used this information to influence classroom conversations.

Summary. According to Piaget (1983), student ideas are the raw material of classroom learning and they may be refined, shaped, revised, connected, and built upon by both teachers and students alike. As opposed to being viewed as obstacles to learning that must be overcome, they can be viewed as assets. It is worth noting that the framework document for the Next Generation Science Standards (NRC, 2012) has placed emphasis on students' ideas to be used in this manner:

> Some of children's early intuitions about the world can be used as a foundation to build remarkable understanding, even in the earliest grades. Indeed, both building on and refining prior conceptions is important in teaching science at any grade level. (p. 30)

As mentioned previously, the resources present in students' alternative conceptions can be leveraged (e.g., Rivet & Krajcik, 2008) with different instructional strategies. Different models of conceptual change have generated specific recommendations for instruction (e.g. Osborne & Wittrock, 1983; Posner et al., 1982), but some strategies (e.g. in-depth interviews with students) might seem too time-consuming for implementation in today's classroom. In addition, attention to student thinking is a difficult process for science teachers at all levels to learn because of their “participation in the social and institutional systems of public schooling, which encourage framings of teaching in terms of classroom management and curricular coverage” (Levin, Hammer, & Coffey, 2009, p. 152). This inattention to student thinking may also stem from teachers thinking that science is a set of known ideas and students learn science best by receiving correct information (Schneider & Plasman, 2011). Nevertheless, the importance of being aware of students’ worldviews, beliefs, and alternative conceptions cannot be underestimated, and many methods, such as journal writing, concept maps, student questioning, small group work, and word associations, have been proposed as instructional strategies for teachers to use in order to elicit student alternative conceptions (Mintzes, Wandersee, & Novak, 2000; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001; Hovardas & Korfiatis, 2006). Another means for eliciting student alternative conceptions is through the use of concept inventories (CIs). The literature review now transitions to a focused discussion of CIs, since one such CI—the Conceptual Inventory of Natural Selection (CINS) (Anderson et al., 2002)—played a critical role in the second and third (current) studies described here.

Concept Inventories

CIs are “research-based instruments designed to measure student conceptual understanding in areas where students are known (through rigorous research) to hold common misconceptions” (Garvin-Doxas, Klymkowsky, & Elrod, 2007, p. 277). CIs resemble typical multiple-choice assessments with which teachers and students are familiar, but are different in major ways. First, CIs measure concept-level understanding and not factual, procedural learning. This is done with a series of distracters for each question that assesses a concept. Each distracter (or “wrong” answer) represents an alternative conception which has been found (through previous research findings) to be commonly held by students. Secondly, whereas traditional assessments reveal little about what or how students are thinking about a topic, CIs (through their distracters) actually reveal a good deal of useful information about student understanding. Because each distracter reveals where student understanding "has gone astray" (Garvin-Doxas et al., 2007, p. 278), educators can use this information they gain about their students to better plan lessons (e.g., instructional activities and assessments) for conceptual understanding.

CIs were first developed as an instructional tool in the field of undergraduate physics and had a significant impact in advancing the field of physics education research. The force concept inventory (FCI) was the first CI to be developed (Hestenes, Wells, & Swackhammer, 1992). The FCI is a 29-question assessment that focuses on probing students' understanding of Newtonian and non-Newtonian concepts about force. It was designed to measure six conceptual dimensions of the force concept that were considered essential for complete understanding (i.e., kinematics; kinds of forces; the superposition principle; and Newton's first, second, and third laws). The FCI was credited with being the vehicle for implementing important reforms in undergraduate physics education, such as the development of a model of peer instruction (Mazur, 1997). It was also instrumental in demonstrating that student learning gains were greater with interactive pedagogy as compared to more traditional lecture-style methods (Hake, 1998). The FCI aided in promoting discussions about pedagogy in these academic circles. Other CIs, such as the force and motion conceptual evaluation (Thornton & Sokoloff, 1998) were created, but none has had the widespread influence and use of the FCI (Smith & Tanner, 2010).

After the widespread success of the FCI and observing its impact on physics education, biology educators were motivated to develop their own CIs. However, unlike physics educators, biologists have had difficulty generating consensus as to which concepts or overarching ideas are most important to assess (Garvin-Doxas et al., 2007; Michael, McFarland, & Wright, 2008). There are now an increasing number of CIs and other similar assessments available for use for undergraduates, including the previously mentioned CINS (Anderson et al., 2002), the biology concept inventory (Klymkowsky, Garvin-Doxas, & Zeilik, 2003), the genetics literacy assessment instrument (Bowling et al., 2008), and genetics concept assessment (Smith, Wood, & Knight, 2008).

For all their potential in offering an additional form of assessment to teachers, CIs still have issues that warrant consideration. Researchers in physics education, for example, have continually discussed whether or not CIs actually measure the conceptual understanding they are designed to assess (Smith & Tanner, 2010). Among the papers that have discussed this issue (Heller & Huffman, 1995; Hestenes & Halloun, 1995; Huffman & Heller, 1995), there were claims that the FCI was perhaps measuring student intuitions in physics rather than a deep conceptual understanding of the six conceptual dimensions of the force concept. While Hestenes et al. (1995) predicted subsets of the FCI questions would map directly onto one of the six dimensions of the force concept, Huffman and Heller argued a factor analysis of the student responses on the FCI should show such an effect. However, this was not the case. After conducting a factor analysis, the FCI did not yield a robust mapping of test items onto each predicted conceptual dimension (Huffman & Heller, 1995). From these results, Huffman and Heller proposed that the FCI may be measuring student understanding within particular scenarios and not more global conceptual understanding. For example, students may have more familiarity with questions on the physics of hockey pucks and this may explain why these questions group together on a particular component during a factor analysis as opposed to being grouped according to a deep conceptual understanding of what these questions were intending to assess.

Other aspects of CIs may limit their usefulness in assessment. These aspects are the vocabulary CIs use and the format they employ (Smith & Tanner, 2010). Some CIs' use of content-specific jargon may obscure the conceptual understanding the CIs are supposed to reveal. Smith and Tanner describe one CI's use of the terms *positive control* and *negative control* in a question that probes students' understanding of the scientific method. They argue that without a working knowledge of what these terms mean, students would be unable to demonstrate their conceptual understanding of the scientific process and experimental design. Hence, a student's understanding of experimental design would actually go unnoticed because of a jargon-filled question; thus potentially resulting in a threat to a CI's validity and reliability.

Like the FCI, the CINS has had similar discussions surrounding its validity and reliability (see Nehm & Schonfeld, 2008, 2010; Anderson, Fisher, & Smith, 2010). Chief among the CINS's issues is the population on which it was originally validated. Nehm & Schonfeld (2008, 2010) argue that for all the value the CINS's authors claim the instrument possesses, it was originally validated on just one population of students and strongly suggest the CINS needs to be continually explored for its efficacy and generalizability among students from different racial and ethnic groups, geographic regions, socioeconomic and language backgrounds, and content preparations. In a response to Nehm and Schonfeld on this point, Anderson et al. (2010) claimed the CINS has been "appropriate for assessing the knowledge of high school students, biology non-majors and biology majors at ethnically diverse institutions" (p.356). However, Nehm and Schonfeld (2010) countered this claim by asserting none of the findings from such administrations of the CINS have yet been published or peer reviewed.

Another concern surrounds findings from Nehm and Schonfeld's (2008) principal component analysis (PCA), which was conducted on a population of biology majors and examined the internal structure of the CINS by seeing how its different questions mapped on different components (or natural selection concepts in the CINS's case). In contrast to Anderson et al.'s (2002) original PCA sample of community college non-majors, Nehm and Schonfeld did not find strong support "for the different (PCA) components representing distinct evolutionary concepts" (p. 1145). In fact, Nehm and Schonfeld found only one component that "included a highly correlated suite of key concepts" (p. 1145). Anderson et al. (2010) acknowledge that "PCA should be conducted with additional populations to clarify this situation so that items can be refined as needed" (p. 356).

Constructive critics of CIs argue that the close-ended, multiple-choice format of a CI seems, by its nature, give limited insight into how students are thinking about a concept (Smith & Tanner, 2010; Nehm & Schonfeld, 2008, 2010). They reveal a "snapshot" in time and students are not necessarily allowed any opportunity for explanation. If anything, CIs should be administered as pre- and post-tests to allow instructors to observe if student learning was affected in some way.

Summary. If CIs are measuring what they are supposed to be assessing, they can be a valuable resource for teachers and other educators, as opposed to other forms of large-scale assessment, like traditional state tests that do not necessarily probe for deep conceptual understanding (NRC, 2001). The distracter answer choices found on CIs are developed with students' thoughts and ideas in mind, especially since the development was guided by students' rationale for specific responses and analyses of written, open-ended answers to questions (Richardson, 2005).

A teacher's knowledge and value of student alternative conceptions, how this knowledge informs his/her practice, and the methods of eliciting student ideas (e.g., use of the CINS) are the central themes running through the set of studies described here. The literature review now shifts to a discussion of teacher knowledge, specifically pedagogical content knowledge and subject matter knowledge, and how they potentially relate to the teaching of evolution.

Pedagogical Content Knowledge

In one of his seminal articles, Shulman (1986a) described pedagogical content knowledge (PCK) as a unique form of knowledge used expressly for teaching. Specifically, PCK is associated with the topics that are regularly taught in a particular subject area and includes all the analogies, illustrations, examples, explanations, and demonstrations (collectively, knowledge of representations) known to communicate a concept. In essence, this type of knowledge is what distinguishes science teachers from scientists. PCK intersects directly through content and pedagogy, especially in knowing which aspects of scientific concepts students are able to learn and understand at different developmental stages, how to best introduce and represent these concepts, and how to have their students effectively understand them (Loucks-Horsley, Hewson, Love, & Stiles, 1998; Loughran, Mulhall, & Berry, 2004).

PCK originated as one of seven categories that formed a knowledge base for teaching (see Figure 2). While the first four categories of teacher knowledge addressed general and crucial dimensions of teacher education, the remaining three categories were more related to specific content dimensions (Ball, Thames, & Phelps, 2008). *Content* *knowledge* includes knowledge of a specific subject and its organizational structures (Shulman, 1986a; Grossman, Wilson, & Shulman, 1989). In other words, "the teacher need not only understand *that* something is so; the teacher must further understand *why* it is so" (Ball et al., 2008, p. 391). *Curricular knowledge* includes an awareness of the wide variety of programs, instructional materials that are used for the teaching of a specific topic (Shulman, 1986a). Without any doubt, the last of these three content-related categories, PCK, has remained quite influential in teacher education programs over the last 25 years or so.

- General pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that appear to transcend subject matter
- Knowledge of learners and their characteristics
- Knowledge of educational contexts, ranging from workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures
- Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds
- Content knowledge
- Curriculum knowledge, with particular grasp of the materials and programs that serve as "tools of the trade" for teachers
- Pedagogical content knowledge, that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding

Figure 2: Shulman's (1987, p.8) major categories of teacher knowledge.

From its inception, the concept of PCK has always had a focus on the ways teachers represent key ideas and how the representations are informed by student ideas. Effective teachers use a variety of strategies to represent ideas while maintaining the integrity of the subject matter, and adjust according to student understanding (Carlsen, 1991; Grossman, 1990). While some representations are particularly strong and illuminate concepts, other representations, even though they are technically sound, are not as clear and open to students. Focusing on student conceptions and alternative conceptions explains how students understand a concept and is an essential feature of teaching a specific concept (Ball et al., 2008). According to Grossman (1990), “teachers must draw upon both their knowledge of subject matter to select appropriate topics and their knowledge of students’ prior knowledge and conceptions to formulate appropriate and provocative representations of the content to be learned” (p. 8).

Like many major ideas in science education, the definition of PCK has undergone several iterations to include the results of later studies (e.g., Friedrichsen et al., 2009; Park & Oliver, 2008; Magnusson, Krajcik, & Borko, 1999; Hashweh, 2005). For example, Grossman (1990) expanded upon Shulman’s ideas to include two more components to PCK: knowledge and beliefs about purposes, and knowledge of curriculum materials; and Hashweh (2005) proposed that knowledge of topic-specific alternative conceptions which students possess and the strategies used to engage them be part of the pedagogy subcategories Shulman and other PCK scholars have previously described. It also worthy to note that the idea of subject matter knowledge has also undergone different iterations since its original conceptualization as content knowledge to include indicators such as an understanding of the structure and nature of a particular discipline, skill in selecting and translating essential content into meaningful learning activities (Gess-Newsome, 1999a).

Integrative and transformative models of PCK. Different conceptualizations of PCK have also resulted in a variety of models that attempt to represent PCK and other teacher knowledge components. In particular, some models vary in the way the relationship between subject matter [content] knowledge (SMK) and PCK is represented (Kind, 2009a). For example, Grossman’s (1990) and Magnusson et al.’s (1999) models are closely aligned with Shulman's conceptualization in that SMK is a distinct category and PCK is further defined as "the special knowledge used by a teacher to transform his/her SMK to benefit students" (Kind, 2009a, p. 7). Thus, a transformative model is analogous to a chemical compound, in which elements cannot be easily separated (Gess-Newsome, 1999). SMK is a separate component and a teacher uses his/her SMK in constructing PCK for a particular topic.

Conversely, other models (e.g., Marks, 1990; Fernandez-Balboa & Stiehl, 1995; Koballa, Gräber, Coleman, & Kemp, 1999) integrate SMK fully into their conceptualizations of PCK. Like the former "transformative" models, these "integrated" models arose from empirical studies, where teachers never described their teaching in terms of transforming their own personal SMK. Rather, the teachers seemed to integrate SMK into their teaching practices when describing their work in terms of pedagogy, student ideas, and context (Marks, 1990; Fernandez-Balboa & Stiehl, 1995). These teachers' SMK and PCK were not clearly distinguished within the teacher knowledge base. To use Gess-Newsome's chemical analogy once again, integrative PCK models are akin to chemical mixtures, in which components retain their original identities, but are indistinguishable on a larger, more macroscopic level. According to Kind (2009a), these integrative models tend to include components that reflect more general teaching knowledge, but may lack explanatory power because no mechanism is suggested for how the interaction between SMK, pedagogy, and context results in PCK (see Abd El-Khalick, 2006).

As mentioned previously, Grossman's (1990) and Magnusson et al.'s (1999) models are transformative. These researchers believe that combinations of knowledge components create PCK, but that SMK is separate (see Figure 3). A teacher will possess

SMK and intend to transform it for the benefit of students' learning by using his/her PCK, which may combine four or five components (e.g., Magnusson et al., 1999; see Figure 4). According to these models, each of the individual components requires subject-specific knowledge. For example, orientations and knowledge of assessment will differ for chemistry and world history teachers. Transformative models suggest a mechanism exists that converts SMK to PCK, uses SMK to create PCK, and/or adapts SMK for classroom use (Kind, 2009a). That is, a highly skilled content teacher will have a way of developing his/her PCK.

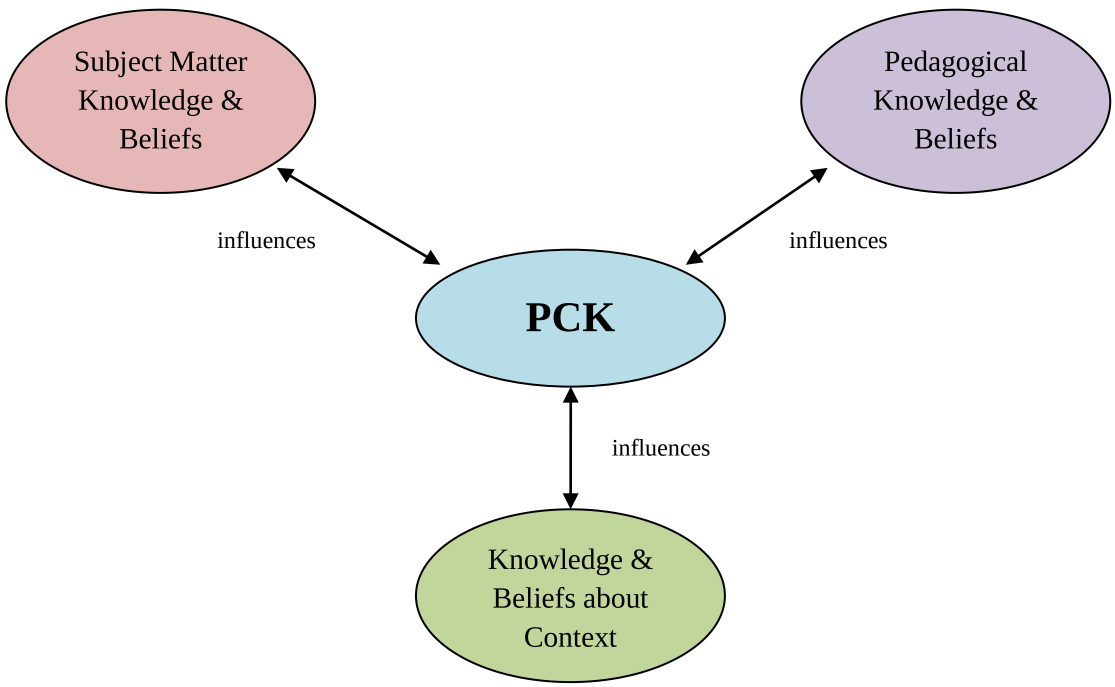


Figure 3: Magnusson et al.'s (1999) model of the domains of teacher knowledge and their relationships [modified from Grossman's (1990) model].

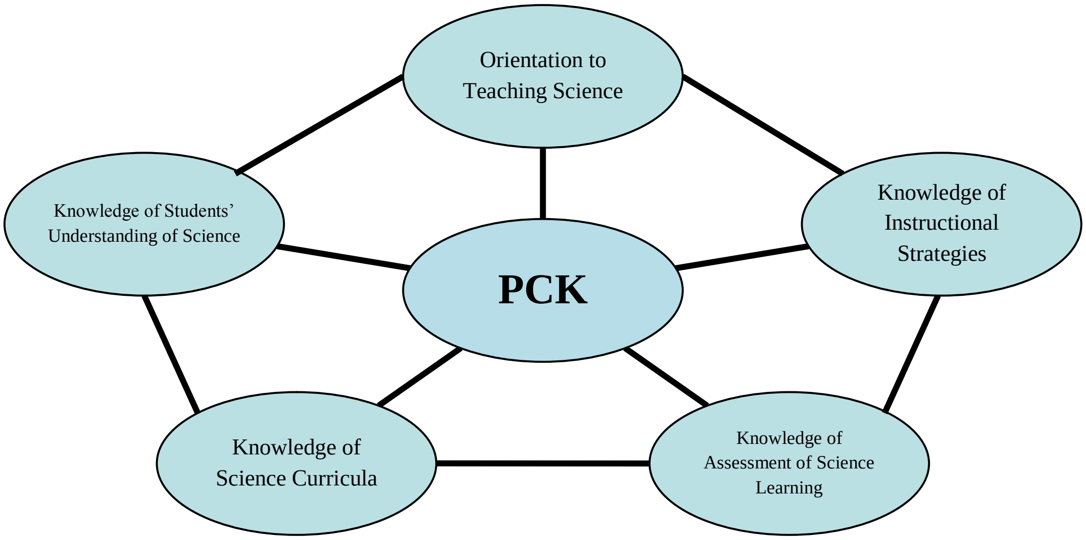


Figure 4. Magnusson et al's (1999) components of PCK for science teaching.

It is with interest to point out that, according to Figure 4, the components of Magnusson et al.'s (1999) model get filtered through the *orientation to teaching science* component. That is, this particular area shapes the content and development of other PCK components. Therefore, any study that attempts to investigate one or all aspects of this model should include *orientation to teaching science* as part of its design (Friedrichsen, van Driel, & Abell, 2011). In support of Magnusson et al.'s placement of *orientation to teaching science* as a filtering or shaping mechanism, the research literature has focused on several important aspects of teachers' beliefs. They include: 1) conceptions of science teaching and learning, in which teachers describe the role of teachers and students and how students learn science; and 2) the purposes and goals of science instruction (Friedrichsen et al., 2011).

Studying PCK in practice. The set of studies described here (in particular, study #2 and current study) examine teachers' PCK within the context of an overarching concept in biology. In this respect, the studies presented here distinguish themselves from many others in the PCK literature in that various studies have researched how PCK manifests itself during teaching practice and many use physics and chemistry concepts as contextual backdrops due greatly to the problematic nature of teaching some of these concepts according to some researchers. These studies suggest three common factors contribute to the development of PCK. The first required factor is possession of good SMK (e.g., van Driel, de Jong, & Verloop, 2002; de Jong & van Driel, 2004; Halim & Meerah, 2002). To some extent, SMK provides a solid foundation on which PCK can develop. After all, for many prospective teachers, one of the main reasons for entering the teaching profession is the opportunity to communicate ideas about a favorite content area to others. The second important factor is classroom experience (e.g., Sperandeo-Mineo, Fazio, & Tarantino, 2006; Angell, Ryder, & Scott, 2005; Lederman, Gess-Newsome, & Latz, 1994). These studies highlight major changes that occur in the early months and years of working as a teacher in that the teachers' perceptions of science adjust from knowing the subject at a very high level to recognizing how the subject is understood and interpreted in a school context. The teachers in these studies learned to adapt their subject matter expertise by taking students' needs and ideas into account. Lastly, emotional factors play a role in developing PCK (e.g., Burn, Childs, & McNicholl, 2007; de Jong, 2000; Childs & McNicholl, 2007) in that personal self-confidence and the opportunity to work in a supportive atmosphere where collaboration is encouraged seems to benefit both novice and experienced teachers.

Detailing the relationship between SMK and PCK. There is little doubt that SMK has an effect on classroom practice. However, debate proceeds when discussing the extent to which SMK and PCK should be considered as separate components of teacher knowledge. There are studies which regard SMK and PCK as distinct components (e.g., Sanders, Borko, & Lockard, 1993; Childs & McNicholl, 2007; Gess-Newsome & Lederman, 1995; Kind, 2009b) and those which suggest SMK and PCK are not entirely separate, but not quite combined, components (e.g., Ball, 2000; Deng, 2007).

In an example of a separate component study, Sanders et al. (1993) researched the practices of three experienced teachers when they were teaching within and outside their respective content areas. They found that when the teachers were planning within their content areas, the teachers knew how to present the key concepts in an organized and logical manner, how much content to present at any one time, and the various interrelationships that existed between different parts of the subject matter. The teachers also realized that their SMK had to be transformed for their students. However, when they were planning outside their content areas, the teachers had difficulty with many aspects of how the content fit within the school context. That is, there were difficulties with sequencing of lessons and recognizing how different concepts were related to one another. Whereas the teachers demonstrated confidence before when teaching within their content areas, the teachers became uncertain and often changed lesson plans at the last minute when teaching out of area. In essence, these content experts became novices in certain aspects of their teaching practices and learned unfamiliar content along with their students. Coupled with learning how to teach unfamiliar content, these weaknesses in SMK had an impact on classroom practice.

Gess-Newsome and Lederman (1995) also reported teachers' knowledge had an effect on how different concepts were taught with a group of biology teachers who had a range of teaching experience. Overall, these teachers' level of content knowledge was rather "fragmented" and the teachers expressed doubt about their ability to present different biological concepts as part of an integrated whole. Teachers had less difficulty with making more real-world connections and integrating a wider range of knowledge when teaching aspects of the content area in which they claimed greater expertise.

Overconfidence with content can have its issues as well. When Kind (2009b) compared pre-service teachers' perceptions of their teaching within and outside content specialization, she found that perceived possession of good SMK can result in overconfidence, which in turn may translate to lessons with poorer quality than those lessons that were taught outside the content area. Not surprisingly, many of these pre-service teachers discover that they have become too specialized in a particular content area and experience conflict when trying to sort out the information needed to teach effectively. Nathan and Petrosino (2003) had a similar finding when examining the relationship between the subject matter expertise of 48 pre-service secondary mathematics teachers and their ability to predict students' learning difficulties associated with solving algebra problems. The researchers posited subject matter expertise alone was insufficient for predicting students' difficulties as learners and to understand how students learn content. The pre-service teacher participants were well versed in mathematics content but not sure of how to most effectively represent content for students to facilitate student learning.

These cases may very well indicate instances where teachers have not yet realized that SMK needs to be transformed for school use. When teaching outside their respective content areas, the pre-service teachers learned the content along with the students and were eager to find a wide and rich range of resources (which included experienced teachers) to develop and teach their lessons.

In studies that claim SMK and PCK are not completely separate categories of teacher knowledge, the boundary between these two categories appears indistinct. Ball (2000) reports that teachers are expected to meet the challenge of integrating SMK and PCK by themselves, and this process can be quite difficult and frustrating for many teachers. She argues that the content knowledge a teacher possesses for teaching should be identified by taking the work teachers do and the role SMK plays in that work into account. She further argues that SMK needs to be viewed from the students' perspective, such as, what is it that the students know and what are their difficulties with the topic. She claims that providing more opportunities for teachers to study more science, math, or any other subject will not necessarily make teachers have improved PCK, but instead indicating what sort of SMK is needed and how make use of it is more effective for teachers' practices.

Essentially, it remains unclear as to whether or not SMK is part of PCK. Deng (2007) offered a way of viewing these aspects of teacher knowledge by creating "academic SMK" and "school SMK". In this way, there is acknowledgement that there are differences between the academic disciplines of science and science in school contexts. Banks, Leach, & Moon (2005) argued that science for school contexts is an important feature of PCK that helped to bridge the gap between subject knowledge and pedagogic knowledge. Further categories of PCK have been developed to facilitate this perspective, such as domain- and topic-specific PCK, which both recognize how a topic is taught and the role academic training plays in shaping a teacher's knowledge base (Veal & Makinster, 1999).

Assessment of PCK. Science teachers' practices are complex and different studies have reported a variety of methods to assess their PCK. Some studies have investigated how teachers teach science in classroom settings by using standard, well-established methodologies or specific rubrics designed for a particular classroom context (e.g., de Jong & van Driel, 2005; Loughran, Mulhall, & Berry, 2004; Lee, Brown, Puthoff, Fletcher, & Luft, 2005). These studies tended to collect data over an extended period of time, as opposed to trying to represent PCK that is captured in one instance. There are also studies that utilize “prompts” to assess PCK. In these studies PCK is investigated by having teachers watch videos and/or read lesson transcripts, and the teachers then report on the perceived PCK (e.g., Ahtee & Johnson, 2006; Veal, Tippins, & Bell, 1999). “Prompt” studies can also take on the flavor of using interventions, where changes in PCK are investigated following attendance at a professional development or some other training course (van Driel, de Jong, & Verloop, 2002; Justi & van Driel, 2005).

In an example of a study that utilized well-established data collection methods in social science research to capture PCK, de Jong and van Driel (2004) collected data over a period of one year. Through a series of pre-lesson interviews that focused on lesson planning and post-lesson interviews that had pre-service chemistry teachers reflect upon teaching and learning, the researchers found the pre-service teachers had little awareness of potential lesson pitfalls, but the process of teaching greatly enhanced their perceptions of the difficulties associated with teaching abstract chemical concepts. This finding could be attributed to the pre-service teachers’ content expert SMK, and that with more experience, they could better integrate pedagogy with their chemical knowledge, thus strengthening the bond between SMK and PCK.

Studies like the one described above provide a rich description of how PCK is used in a specific context. The use of multiple methods to collect data means that more meaningful triangulation is possible because the different data sources can be examined and corroborated for common patterns and themes, thus creating sound reliability and validity (Kind, 2009a). However, collecting data in this manner is rather labor intensive, which is why many of these studies take place among teacher education programs, studying a focused segment along the developmental pathway of teachers—the pre-service teacher. Therefore, completing projects like these are difficult endeavors, especially with in-service teachers in less well-studied school environments. In studying science teachers' PCK in an under-utilized school site, the research presented here (especially study #2 and current study) approached data collection in this challenging manner, in particular because studies like these are vital to the research base, as common factors consistently emerge regardless of context (Kind, 2009a).

Prompt-style studies use video excerpts or descriptive prompts as standard instruments for investigating PCK. Teachers are exposed to the video or prompt and then asked to respond (through one or more data collection instruments) and reveal their PCK through the prompt material. In one such study, Veal et al. (1998) used descriptive vignettes as prompts in a longitudinal fashion by having pre-service teachers respond to these prompts on four separate occasions. Using the vignettes longitudinally gave the researchers a better understanding of how PCK evolved and changed over time.

These prompt-style studies have the advantage that the prompts can be adapted for use in a wide range of settings (Kind, 2009a). Teachers in varying contexts, with different backgrounds and levels of experience, can all be invited to respond, thus allowing researchers to compare PCK and its development across different situations and contexts. However, there are disadvantages as well. One such disadvantage is that the full range and quality of a teacher's PCK may not be exposed through this methodology, that is, it is a “snapshot” representation, especially if the prompt is used only once. Nevertheless, in some cases, this may be the intention of the researcher, particularly if the goal of the investigation was to see how different teachers respond to a student’s alternative conception on a certain science idea.

Intervention studies allow researchers to investigate teachers’ PCK before and after participation in a particular event or series of events. Here, a certain aspect of PCK is featured as part of the intervention and the goal of these studies is to prompt the development of PCK. These studies, like the previously-mentioned prompt-style studies, have the advantage of being useful with a wide range of teachers and researchers can adapt their data collection methods to the participants’ contexts and situations. In addition, these studies are appropriate for evaluating the effects of continuing professional development on teachers’ practices. However, these studies have limitations. Namely, investigation of long-term effects on teachers’ practices may not be possible due to the short-term nature of the intervention. While the set of studies described here do not investigate long-term longitudinal effects of an intervention, they are not short-term in nature either. The research studies presented here are extensions of each other and of value because they provide an examination of PCK dynamics of one instructional unit through the perspectives of various teachers at one campus.

Overall, assessing PCK is a complex undertaking and science-oriented PCK research has tended to divide these studies into two broad categories: tracking the longitudinal, developmental changes in PCK and describing the PCK that already exists by investigating and recording how teachers “act” in a given situation (Kind, 2009a). By capturing how teachers are planning and what they are doing in their classrooms for an extended period of time, the current study adopts the latter approach by investigating a group of biology teachers' individual PCK for teaching evolution.

Summary. Based on over 20+ years of research, there is strong evidence that PCK is a well-utilized concept for contributing to an understanding of teacher knowledge. With its many different interactions, PCK's nature is inherently complex--perhaps more so than Shulman originally thought. Nevertheless, it has value to the teaching profession and those who study the field.

Models that accurately represent PCK continue to be developed (e.g., Park & Oliver, 2008; Park & Chen, 2012), although development remains challenging due to PCK's innate intricateness. Various research findings remain inconclusive about integrative and transformative models of the PCK-SMK relationship, but transformative models are increasingly common in science education research because of their explanatory power in subject-specific contexts. Research also suggests that PCK models need to adjust for experience levels across different domains (Appleton, 2006) because more experienced teachers will tend to think of PCK as encompassing SMK and not as distinct components of teacher knowledge. This re-structuring of SMK may be due to teachers adapting their personal, prior specialized knowledge to school use as they go beyond the initial phases of induction (Kind, 2009a).

It is not the intention of the current study to attempt to explore all the dynamics of the complex PCK-SMK relationship. Rather, this study focuses on interactions of four aspects of the teacher knowledge base: *subject matter knowledge and personal beliefs, orientation to teaching science, knowledge of students' understanding of science* (specifically *areas of student difficulty* and *alternative conceptions*), and *knowledge of instructional strategies*. The focus on how these different aspects interact with one another is consistent with research that calls for an attempt to understand the interaction of teacher knowledge components and how they relate to one another in addition to examining individual components (Abell, 2008; Friedrichsen et al., 2011).

The next section of this chapter now focuses on a discussion of teaching evolution since its context is used as the setting for the set of studies described here. The discussion will center on how the topic relates to some of the relationships that have been mentioned thus far, particularly between SMK and personal beliefs.

Personal Beliefs, Knowledge, and the Teaching of Evolution

A variety of research studies has consistently reported the prevalence of difficulties pre-service and in-service teachers experience with evolution (e.g., Asghar et al., 2007; BouJaoude et al., 2011; Deniz, Donelly, & Yilmaz, 2008; Kim & Nehm, 2011; Nehm & Schonfeld, 2007; Rutledge & Warden, 2000; van Dijk, 2009). Many of these difficulties have been attributed to religious views (Alters & Nelson, 2002; Asghar et al., 2007), misconceptions and prior ideas about evolution (Gregory, 2009; Meir, Perry, Herron, & Kingsolver, 2007), limited acceptance of evolution (Bishop & Anderson, 1990; Kim & Nehm, 2011; Rutledge & Warden, 2000; Berkman & Plutzer, 2011), and a lack of understanding of NOS (Dagher & BouJaoude, 1997, 2005; Kim & Nehm, 2011; Rutledge & Warden, 2000; Rudolph & Stewart, 1998; Scharmann, Smith, James, & Jensen, 2005).

The relationship between the understanding and acceptance of evolution is an often-studied topic in evolution education research, but the research has yielded some inconclusive results (Akyol, Tekkaya, Sungur, & Traynor, 2012). For example, some studies (e.g., Deniz et al., 2008; Rutledge & Warden, 2000) have reported a positive and direct relationship between understanding and acceptance of evolution, but others (e.g., Bishop & Anderson, 1990; Sinatra, Southerland, McConaughy, & Demastes, 2003) found no association between the two. Even though Deniz et al. (2008) found a somewhat low direct positive relationship, they cautioned that the understanding of evolution should not be heavily overstated when explaining the variance seen in accepting evolution. They suggested that teachers' religious orientations and views on NOS should also be considered. The cautionary statement from Deniz et al. is consistent with other researchers' realizations that the understanding of evolution is not necessarily closely related to the acceptance of evolution.

As a consequence of such research, there has been a call for studies that explore other constructs that possibly play an influential role in the understanding and acceptance of evolution. A deep understanding of NOS soon appeared as one of these constructs. As a result, different studies have indicated deep NOS understanding is necessary for the understanding and acceptance of evolution (e.g., Clough, 1994; BouJaoude et al., 2011; Dagher & BouJaoude, 1997, 2005; Kim & Nehm, 2011; Rutledge & Warden, 2000). In one of the earlier studies, Clough (1994) suggested that the public debate between evolution and creationism could be mainly traced back to the misconceptions related to NOS. Whereas Sinatra et al. (2003) found that undergraduates' acceptance of scientific knowledge's tentativeness was certainly related to their acceptance of human evolution, but interestingly, not with the acceptance of animal evolution. Sinatra et al. (2003) concluded that accepting human evolution, which is regarded as particularly tentative by many nonscientists, was significant for approving the overall tentativeness of scientific knowledge. Similarly, in their study with in-service teachers, Nehm and Schonfeld (2007) found that even when the participants increased their knowledge of evolution and NOS, it did not have a significant influence on their preference for teaching evolution and most of the teachers still chose to teach antievolutionary ideas. Nehm and Schonfeld suggested that some sort of minimal threshold of knowledge of evolution and NOS may have been needed to change the teachers' preferences, but it was still not enough to reduce their antievolutionary ideas.

The effect of both knowledge and belief has had a substantial effect on evolutionary instruction. As highlighted by many researchers, evolution has not been given adequate emphasis during instruction (e.g., Aguillard, 1999; Rutledge & Mitchell, 2002; Moore, 2007; Moore & Kraemer, 2005; Shankar & Skoog, 1993; Trani, 2004) and there are several reasons for such avoidance in science classes. Among the reasons both pre-service and in-service have given are: 1) inadequate content knowledge or SMK (Asghar et al., 2007; BouJaoude et al., 2011; Griffith & Brem, 2004; Nadelson & Nadelson, 2010); 2) insufficient PCK or knowledge about specific strategies to teach evolution (Asghar et al., 2007; BouJaoude et al., 2011); conflicting views between evolution and religious beliefs (Asghar et al., 2007; BouJaoude et al., 2011; Sanders & Ngxola, 2009); and 4) the type of school in which instruction occurs (Asghar et al., 2007). All of these reasons have an influence on teachers' instructional decisions when teaching evolution. In order to teach evolution effectively, teachers need to be able to feel comfortable and confident in their knowledge and abilities to teach evolution. In their study that demonstrated teachers' confidence in teaching evolution, Griffith and Brem (2004) found that when biology teachers participated in a workshop in which they learned the most recent information about evolution, it enhanced their confidence with teaching evolution. Similarly, in their study of 415 pre-service science teachers, Akyol et al. (2012) found that higher levels of understanding and acceptance of evolutionary theory were associated with stronger confidence for teaching evolution effectively.

Summary. Within the context of evolution, the prospect of investigating the relationship between teachers' SMK and PCK becomes even more necessary because so many alternative conceptions surround this topic. Other scientific topics notwithstanding, evolution's abstract nature and issues with beliefs and knowledge make it an ideal context in which to explore these interactions. Figure 5 highlights the relationships that are under further investigation in the current study.

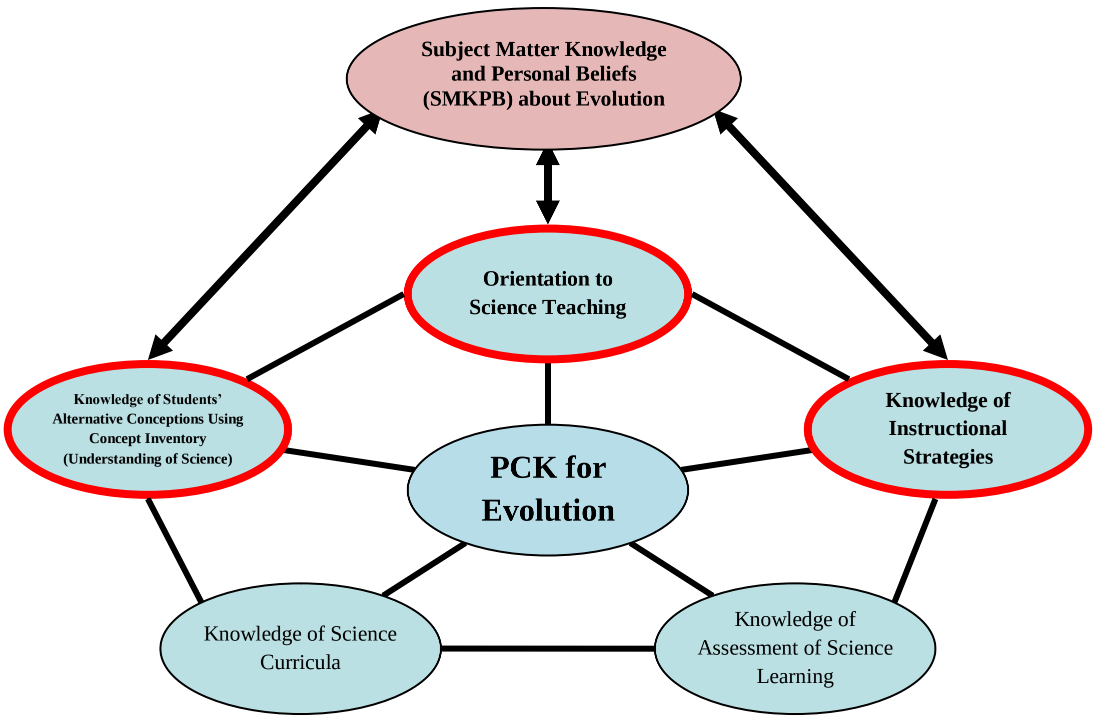


Figure 5: Working representation of relationship under investigation in current study between SMKPB and specific areas (outlined in red) of PCK for teaching evolution using Magnusson et al.'s (1999) model.

Magnusson et al.'s (1999) model is transformative in the respect that SMK is not integrated into PCK, but represents SMK and personal beliefs (PB) as informing all aspects of PCK and vice versa. The representation seen in Figure 5 highlights important and relevant constructs discussed thus far and which are appropriate for the current study. In addition to orientation to science teaching and knowledge of instructional strategies, the fundamental theme cutting across this entire research line of inquiry is the knowledge and awareness of students' alternative conceptions. The discussion above described the importance of using alternative conceptions as resources in learning and there is little doubt that alternative conceptions with regards to evolution may be particularly accessible to teachers because the conceptions are quite numerous. However, based on previous research, it is also quite apparent that many teachers are uncomfortable teaching evolution and for a variety of reasons ranging from a naïve view of NOS to a lack of specific deep conceptual understanding, students may never receive opportunities to explore the validity of their conceptions with regards to this topic. The majority of the studies presented here employed the use of a concept inventory to elicit student thinking on evolution's main mechanism of natural selection. Teachers may or may not be aware of the available instructional strategies that can elicit alternative conceptions, but using a concept inventory can help to provide insight into what students are thinking on the topic of evolution.

The next two chapters detail the two pilot studies that led to study #3 (the current study). The first pilot study simply set out to gauge students' understanding of various NOS and evolutionary concepts through the use of four inquiry-based lessons. Therefore, it describes and tracks student thinking of evolutionary and NOS concepts during an instructional unit. The second pilot study is a rich qualitative description of how a group of biology teachers from the same high school campus went about identifying and addressing their students' alternative conceptions when teaching evolution concepts during an instructional unit.

Chapter Three: Pilot Study #1

The purpose of pilot study #1 was to track the path of high school students' evolutionary and NOS thinking when participating in an intervention consisting of four 90-minute inquiry-based lessons centered on the topics of: 1) NOS (two lessons); 2) adaptation; and 3) natural selection. This particular group of lessons created an opportunity to explore student thinking of evolutionary and NOS concepts. The instructional unit included lessons modified from Passmore and Stewart's Modeling for Understanding in Science Education (2002, http://www.wcer.wisc.edu/ncisla/muse/), a lesson on adaptation, and Robert Gendron's (2003) natural selection simulation. More specifically, the research questions were:

P1.1 What is the path of students' thinking when participating in an instructional unit focused on evolution and NOS concepts?

P1.2 What knowledge gains (if any) do students experience at the conclusion of such an instructional unit?

Context

Classroom instruction took place at an urban high school in west Texas during the summer of 2009. The instructional unit consisted of four 90-minute inquiry-based lessons on evolution and natural selection, along with an introduction that included a NOS component. While the intervention could have included additional lessons on other evolutionary topics, such as fossils, homologous structures, and other evidence for evolution, the unit of lessons maintained a tighter focus by concentrating on specific subtopics of evolution directly tied to its processes and mechanisms, such as adaptation and natural selection (Mayr, 1982). The time frame of four 90-minute lessons characterized what most secondary biology classes in Texas use to introduce the topics of evolution and natural selection typically in the second semester of the academic year. Furthermore, evolutionary concepts are traditionally taught as an individual discrete topic among many through the course of the year. All the lessons within the unit were taught by me, the principal researcher and former high school biology teacher.

Lessons #1 and #2: The nature of scientific arguments and the nature of explanatory models. The first two lessons focused heavily on NOS and were modified from Passmore and Stewart's evolution unit (2002). The first lesson concentrated on the nature of scientific arguments and was mainly designed for the purpose of having the students understand that not all scientific practices are based on experimental manipulation. Certain sciences, including biology, involve a strong element of historical reconstruction, and this historical reconstruction involves making inferences about past events using data that is available today. In addition to having the students understand that scientific inferences are based on data (observations), prior knowledge, and beliefs, this lesson was also designed to create a climate of scientific discourse among the students where arguments are respectfully critiqued based on disagreements with data, prior knowledge and/or beliefs used.

To focus on the roles data, observations, and prior knowledge and beliefs (PKB) play when scientists attempt to reconstruct historical events, the students were asked to sequence and create a story around a series of cartoon frames. The cartoon frames were rooted in two stories from children's literature—*Three Little Pigs* and *Little Red Riding Hood*—and represented "snapshots" in time with noticeable gaps (just as the fossil record does), and the students worked in groups of three or four to place the frames in a sequence that made sense to them. The fact that the cartoon frames had imagery from children’s literature was completely intentional, as this activity, according to Passmore and Stewart (2002), provided a scientifically "neutral" context with which to work and allowed the students to begin their study on a more or less level playing field (all of them were familiar with these children’s stories). During this time the students were instructed to be mindful of the decisions their respective groups made to reconstruct the sequence and pay particular attention to the PKBs that informed those group decisions about placement.

The connection between this activity and the fossil record was continually emphasized in that scientists, themselves, bring their own PKBs when interpreting fossil evidence and healthy scientific discourse ensues when they try to evaluate fossil evidence and modify the fossil sequence. After constructing their sequences the groups presented their respective sequences to their peers and answered questions from them as a whole-group discussion. In order to assess the students’ ability to identify observations, PKBs, and inferences, the last task of this lesson asked the students to read a brief section of writing from naturalist David Attenborough, identify the data and inferences included in the paragraph, and list at least one belief or piece of prior knowledge used to make any of the identified inferences.

The second day’s lesson focused on the nature of explanatory models. This lesson was an extension of day one. The theme of identifying observations, inferences, and PKBs was evident in that these three “ways of knowing” collectively serve as the basis for scientific explanatory models, such as models for DNA structure and predator-prey interactions. This lesson was designed for students to examine this relationship and analyze three different explanations for how biological species have come into/passed out of being on Earth. The students were asked to examine Paley’s intelligent design model, Lamarck's use and disuse model, and Darwin's natural selection model from the perspective of each of these three men. After highlighting the main points of each argument and considering, as a class, how each of these men would account for the origin of the eye, the students were then asked to explain how each man would account for the presence of numerous pigeon varieties given that they are all members of the same species.

Lesson #3: Adaptation. A focus on Darwin's natural selection mechanism of evolution began with the third day's lesson on adaptation, which was modified from a widely used data-collecting activity that concentrated on various insects' camouflage traits. An adaptation is classically defined as a heritable trait that increases an organism's fitness in its environment and evolves by natural selection. Inherent in adaptation's definition is an understanding of biological fitness, which is defined as the ability for an individual organism to reproduce, and yet, the concept of biological fitness tends to yield its own set of student preconceptions. During the data-gathering activity students assumed the roles of predators trying to capture cryptically- and conspicuously-colored insect prey and they used their data to interpret the relationship between having an adaptation and survivability. As specific tasks related to evolutionary thinking, the students were asked to self-evaluate their conceptions of "fitness" and compose group definitions of "adaptation" after observing the effects (from the data-gathering activity) of possessing a particular adaptation and writing individual definitions of the term.

Lesson #4: Natural selection. The last lesson on natural selection was based on a simulation developed by Gendron (2003), which tracked the evolution of two traits (camouflage and visual acuity) in predator and prey populations. This lesson was designed for the students to gain an understanding of the mechanisms of how natural selection actually works. One of the tenets of Darwin's model of natural selection is that populations are made up of organisms that exhibit variation from one individual to the next. In addition, of these variations, some are advantageous while others are not. Even though these are basic principles and students will almost always affirmatively agree with them, when asked again how natural selection works, they usually fail to "set the stage" with the variation of a population. Many biology educators assume their students can conceptually explain variation, and thus, mention variation only in passing. Variation is rarely investigated and when it is, little attention is paid to its complexity and how it lays the foundation for how natural selection works. After providing the students an overview of Darwin's model of natural selection, the students performed an activity that was suggested by Passmore and Stewart (2002) which involved demonstrating variation within a population of sunflower seeds. The natural selection simulation built on this understanding of variation as it modeled the evolution of the two previously mentioned traits over several generations. Specifically, the students were asked to describe the trends/patterns they observed with the two traits during the simulation and provide a hypothesis for these trends/patterns. In addition, the students were asked to relate their data to the process of extinction and, in turn, extinction to population variability.

Participants and Data Sources

The participating students ranged in age from 16 to 18 years old, were recruited from the school's computer-based credit recovery program, and had taken one year of general biology, but had failed or lost credit for some science course during the previous year(s). There were five students who were consistent in their attendance for the duration of the unit and the data used in this study reflects the responses from these students.

The sources of data used in this study included: (a) daily classroom observations, (b) written pre- and post-assessments, and (c) classroom artifacts. Classroom artifacts were the dominant means of data collection. Examples of artifacts included justifying group decisions with regards to sequencing cartoon pictures, which models real work when fossils are sequenced; individual and group definitions for the term “adaptation”; being able to identify and explain the trends and patterns observed during the natural selection simulation; and explaining how extinction is related to population size in terms of variability and the types of geographic areas in which extinction events tend to occur.

Data Analysis

Data analysis was accomplished by isolating and defining which lesson tasks dealt specifically with evolutionary and NOS concepts. A total of nine tasks dealt with these concepts. All tasks are described in Appendix A. A coding rubric was then developed for each of these tasks to determine the students’ level of evolutionary and NOS knowledge. Table 1 shows an example of the specific coding rubric used (modified from Kampourakis & Zogza, 2009) for the pre- and post-assessment tasks which assessed evolutionary thinking. Table 2 shows an example of a specific coding scheme for one of the NOS tasks. Appendix A shows the actual task that was given as the pre- and post-assessment.

0	no explanation is offered
1	incorporates creationist/supernatural/unnatural/intelligent design ideas in explanation

2	incorporates Lamarckian ideas in explanation; explanations that refer to a plan, a purpose or a goal, whether referring to population-level or individual-level events; includes explanations referring to crosses between individuals from different species, to the influence of the environment on individuals as well as to the effect of use and disuse on individuals
3	explanations that refer to the past, to the existence of a common ancestor or to features that existed in older species as well as to population level events; incorporates natural selection concepts in explanation

Table 1: Coding rubric for pre- and post-assessment task of "How might a scientist explain how tortoises with the 'saddleback' carapace came to be? Please give a detailed explanation."

0	did not identify a decision/inference student's group made about how cartoon cards were sequenced
1	identified a decision/inference, but offers little explanation about group's reasoning
2	clearly identifies a decision/explanation and describes group's reasoning for making this inference

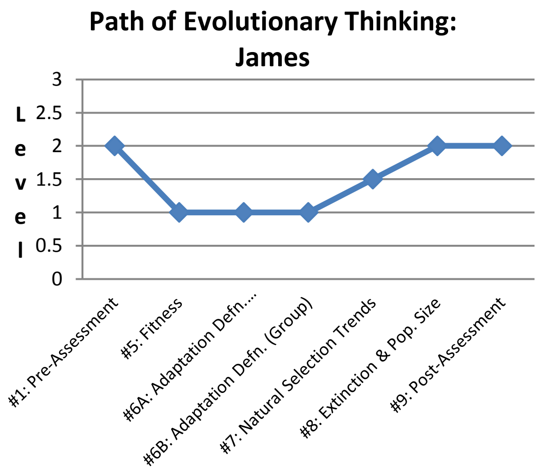
Table 2: Coding rubric for NOS task of "Describe one decision (inference) your group made about the order of the cards in terms of the data (observations) you used and the prior knowledge and beliefs (PKBs) you brought to bear in developing the sequence of cards."

Once all of the tasks were identified each student response from each specific task was categorized and coded for level of evolutionary and NOS thinking by the principal researcher who was a doctoral researcher in the area. The data from each student were analyzed separately, and all instances of evolutionary and NOS conceptual thinking were tracked for each student.

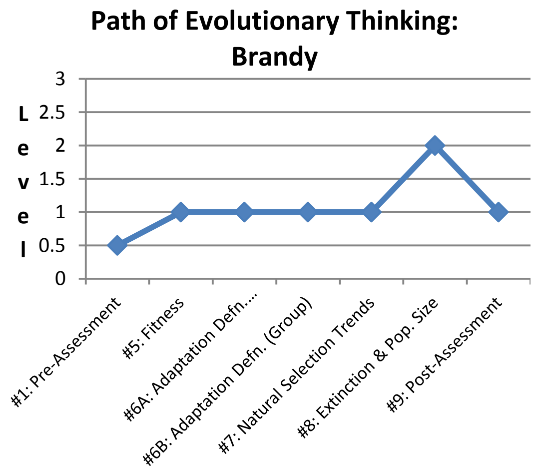
Results

The results display the path of student evolutionary and NOS thinking that actually took place during the intervention, based on students' responses to specific tasks. Figure 6's patterns were the result of coding each student's responses to specific evolutionary tasks. Attention should be drawn to three features of these patterns. First, students' responses to particular tasks changed somewhat considerably and inconsistently throughout the unit. Secondly, the level of evolutionary thought with regards to pre- and post-assessment tasks did not vary much. Together, these two patterns undermined assumptions that students learn concepts in a linear manner and knowledge seems to simply “grow” as students are exposed to more concepts. Lastly, students’ responses to tasks regarding adaptation and biological fitness demonstrated conceptual difficulty with these concepts, indicating these students still retained alternative conceptions with these evolutionary ideas. In biology, an adaptation is an inherited characteristic that increases an organism's chance for survival and fitness is the ability of an organism to reproduce. The student responses to these tasks still either exhibited Lamarckian tendencies, or failed to recognize the feature of heritability, and tended to equate the concept of fitness with strength and wellness, not realizing any connection to the ability to reproduce. Even though the results from the intervention seemed problematic, the latter findings that dealt with students’ alternative conceptions provided rich terrain on which to explore and further develop the subsequent research studies presented here.

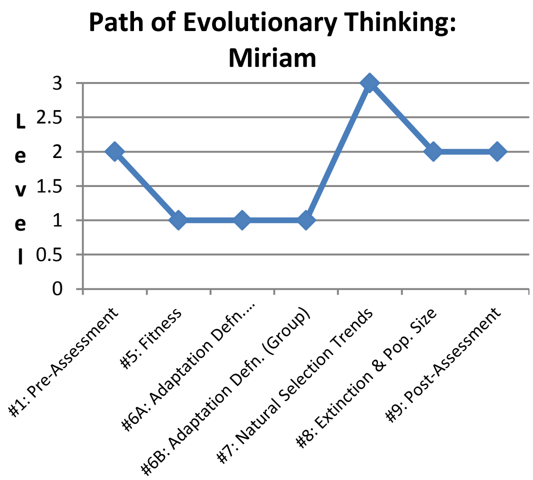
Figure 7 shows the pattern of responses for tasks specifically related to NOS thinking. From here, it is also apparent that NOS thinking did not follow a clear linear pattern, but all of the students seemed to have followed the same type of pattern. The students participated in NOS topics that became increasingly conceptually challenging, beginning with task #3A, “Data Referencing”. Every student demonstrated a marked decline in NOS thinking by the time they reached task #3C, “Prior Knowledge/Belief (PKB) Referencing”, suggesting that these students had little difficulty in identifying scientific data and probably performed this task quite readily in other science classes, but when faced with the task of PKB referencing the students were at a loss with what to do, as indicated with very brief and vague responses. Nevertheless, most of the students managed some understanding of NOS by the time they completed their last specific NOS task, #4A-C, “Explanation of Darwin, Lamarck, & Paley Models”.



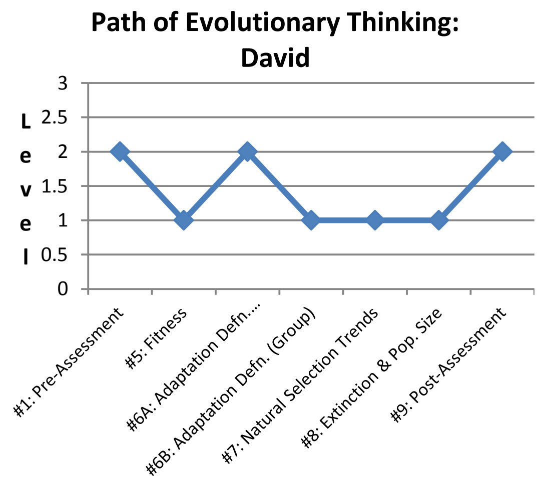
Path of Evolutionary Thinking: James
Level
3
2.5
2
1.5
1
0.5
0
#1: Pre-Assessment
#5: Fitness
#6A: Adaptation Defn.…
#6B: Adaptation Defn. (Group)
#7: Natural Selection Trends
#8: Extinction & Pop. Size
#9: Post-Assessment



Path of Evolutionary Thinking: Brandy
Level
3
2.5
2
1.5
1
0.5
0
#1: Pre-Assessment
#5: Fitness
#6A: Adaptation Defn.…
#6B: Adaptation Defn. (Group)
#7: Natural Selection Trends
#8: Extinction & Pop. Size
#9: Post-Assessment



Path of Evolutionary Thinking: Miriam
Level
3
2.5
2
1.5
1
0.5
0
#1: Pre-Assessment
#5: Fitness
#6A: Adaptation Defn.…
#6B: Adaptation Defn. (Group)
#7: Natural Selection Trends
#8: Extinction & Pop. Size
#9: Post-Assessment



Path of Evolutionary Thinking: David
Level
3
2.5
2
1.5
1
0.5
0
#1: Pre-Assessment
#5: Fitness
#6A: Adaptation Defn.…
#6B: Adaptation Defn. (Group)
#7: Natural Selection Trends
#8: Extinction & Pop. Size
#9: Post-Assessment

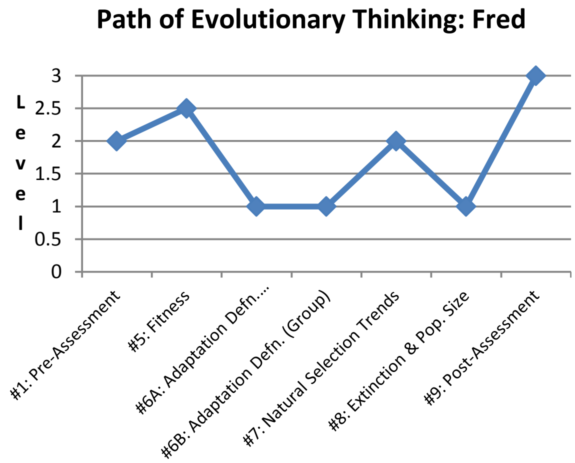
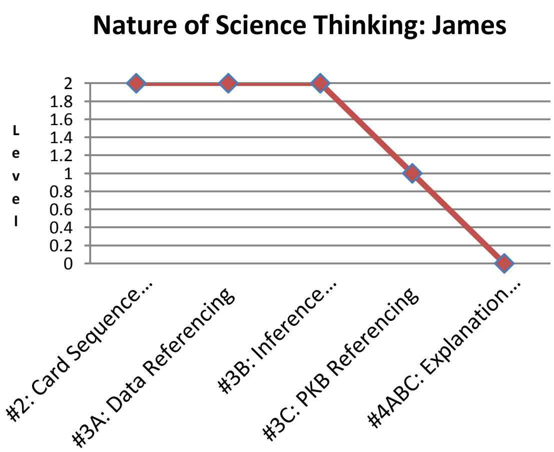


Figure 6: Path of evolutionary thinking based on coding levels of evolutionary knowledge.



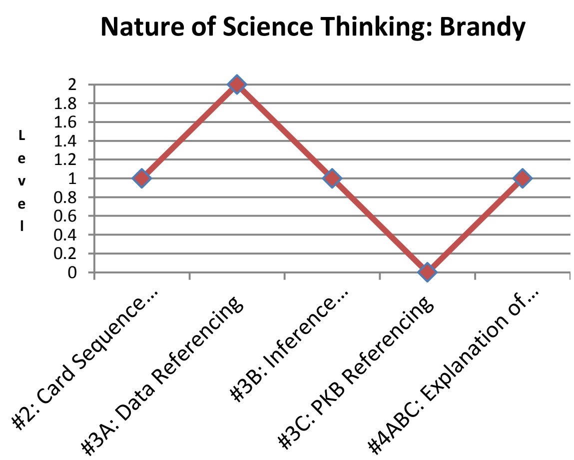


Figure 7: Path of NOS thinking as measured by coding levels.

Lastly, Table 3 shows the students' pre- and post-assessment thinking of how evolution occurs.

STUDENT	PRE-ASSESSMENT ANSWER 6/23/09	POST-ASSESSMENT ANSWER 7/9/09
JOSH	The saddleback more than likely had certain predators and also its body had evolved to fits its surroundings.	The tortoise had to evolve in order to reach the vegetation or the cactus.
DAVID	The "saddleback" came from a rocky beach bed unlike the "dome" which came from sand. The rocky beach bed had altered the way the shell was to form.	They changed in their environment so they could avoid predators. They [the environment] probably got rough-shored beaches.
FRED	Probably what happened is that turtles with long necks started reproducing with other turtles that had long necks and pretty soon the saddleback came to be a species of long neck tortoises that eat from high vegetation.	A scientist might say that the saddleback tortoise came to be because the tortoises' genetics are dominant and are better fitted to their environment.
BRANDY	Scientists would believe that it's evolution and they all developed differently.	Turtles are very slow and can't run from predators, if they move any. They have their saddleback for protection. God made this animal this way for like a shelter for them.
MIRIAM	The tortoises' saddleback shell was created when a domed tortoises' DNA was spliced, causing the genes to change and the carapace to change shape.	The saddleback tortoise's DNA was spliced with the domed tortoise's carapace gene. The genes spliced causing the "saddleback" carapace.

Table 3: Student answers to "How might a scientist explain how tortoises with the 'saddleback' carapace came to be? Please give a detailed explanation".

In general, the students' pre-assessment responses represented two points on a continuum of evolution knowledge. Some responses were very broad and vague in nature (e.g. Brandy's response), with little incorporation of the information presented in the problem, whereas other responses (e.g. Fred's and David's responses) yielded more specifics (albeit still rather general) for how evolution worked with the tortoises. The more specific responses attempted to incorporate some prior science knowledge, but with regards to selection, they still lacked clarity for how the saddleback tortoises evolved. Within this group some responses were gene or reproduction-centered (acknowledging the importance of inheritance) and others were more environment-centered. Despite the still somewhat vague nature of these responses, common alternative conceptions regarding evolution (i.e. single, dramatic mutation event hinted at with Miriam's response; directed variation hinted at with Josh's response) were exposed with this pre-assessment.

Post-assessment responses revealed that they still had a vague sense of how evolution occurs in spite of the instructional unit. Lamarckian misconceptions still persisted (e.g. Josh's answer), some ideas were relatively unchanged (e.g. Miriam and David), and in one case, creationist ideas were revealed (Brandy). Fred's post-assessment answer revealed some conceptual change in that he was expressing ideas about some genes being more advantageous than genes from other populations, thereby hinting at the importance of variation. No mention of deep time concepts was made by any of the students, and this was reflective of the unit not truly integrating deep concepts within its framework.

Discussion

In spite of a small sample size, pilot study #1’s results suggest the sequencing of concepts (i.e., placing lesson on adaptation before lesson on natural selection) plays an integral role in learning about evolution. Many times evolution instruction begins with a lesson on adaptations and then transitions to a lesson on natural selection; however, based on these data, it is apparent that this sort of sequencing may be ill-advised. To gain a full appreciation of how adaptations contribute to evolution, natural selection concepts, such as variation within a population, differential survival, and origin of variation (Anderson et al., 2002), should be emphasized first. Or better yet, throughout the academic year.

Pilot study #1 dealt very much with the actions of students and how they were thinking through a series of evolution concepts. The fact that there were not many knowledge gains from these students after participating in an instructional intervention was rather disturbing and provided evidence that much more was occurring here within the context of this classroom and topic other than a straightforward lack of conceptual understanding (Lucero, 2011). The instructional unit used in this study made strong attempts at incorporating variation, selection, and inheritance into its lessons, but was still taught in isolation relative to other topics, and lacked an incorporation of deep time concepts, thus resulting in little to no mention of deep time in student responses. In addition, student thinking was not probed in a consistent manner that would indicate how subsequent lessons could be further modified. Moreover, it is becoming increasingly evident that a traditional curriculum, which treats topics in isolation, with no unifying theme, is a disservice to students and the entire discipline of biology. With evolution as the common thread that ties all of the instructional units together, students may exhibit less alternative conception use especially when taught with an active-learning strategy as opposed to students who are taught in a traditional lecturing style with only one discrete unit on evolution (Nehm & Reilly, 2007).

In many ways, pilot study #1's instructional unit reflected some of the practices of many secondary biology classrooms, in that deep time was rarely mentioned, too little isolated time was spent with evolutionary concepts, and students' ideas on a topic or concept were not frequently probed either at the beginning or during a lesson. This latter practice had the most influence on which direction the subsequent research studies presented here would take. Student ideas may have been initially gauged with an open-ended task (see Appendix A), but these ideas did not necessarily inform instruction for the rest of the instructional unit. It became clear that more precise information was needed on students' ideas on evolutionary concepts so that these ideas could then inform instruction. I believed this student information could certainly be gathered with a concept inventory, specifically the CINS.

Chapter Four: Pilot Study #2 and Problem Statement

Although pilot study #1 yielded interesting results from the student front, it was time to examine teachers' perspective on this topic. I, as the principal researcher, became intrigued with the notion that teachers' knowledge of their students' evolutionary alternative conceptions could potentially affect how lessons were being implemented. With this thought in mind, an examination of how teaching practice was influenced (or not) by such knowledge became warranted.

Pilot study #2 originated with the realization that recognizing and addressing students' alternative conceptions is a major factor in teaching for better understanding of scientific concepts. Initially (before pilot study #1's intervention), there was an open-ended pre-assessment question students had to answer, but the intervention did not change nor was it modified as a result of learning what the students' alternative conceptions were. Therefore, pilot study #2 had no intervention as part of its design. Its aim was to be purely descriptive by capturing how a group of biology teachers from the same high school campus thought about evolution and went about identifying and addressing their students' alternative conceptions when teaching evolutionary concepts during an instructional unit. Having this information would better gauge the knowledge teachers possess about their students. It would also explain what becomes of such specialized knowledge by how it gets used within the context of a teacher's practice.

Research Questions

The overarching research question guiding this study was: "When teaching an instructional unit on evolution, how does a group of biology teachers identify and address their students' alternative conceptions?" A number of sub-questions arose from this central research question and guided this study. The sub-questions were:

P2.1 What is the nature of these biology teachers' subject matter knowledge with regards to evolution and natural selection, specifically, and how does this knowledge inform their teaching practice?

P2.2 What is the nature of these biology teachers' knowledge of their students' alternative conceptions with regards to natural selection, specifically, and how does this knowledge inform their teaching practice?

P2.3 At the conclusion of the evolution instructional unit do these biology teachers' respective students maintain or modify their alternative conceptions regarding natural selection?

Methodology: Context, Participants, and Data Sources

This study employed a qualitative case study approach and took place in the spring of 2011. Data was collected from the same study site as pilot study #1, with the principal researcher formally observing each teacher's biology classes in rotation. Three teachers participated in pilot study #2, and this group of teachers was a subset of a larger group of teachers (n=6) who were teaching biology at the study site. The participants in this study all had varying amounts of experience. Participants are referred to by the pseudonyms Javier, Carlos, and Joanne. Personal participant data is found in Table 4.

Name	Years of Overall Teaching Experience	Years of Biology Teaching Experience	Number of Biology Classes	Education Background	Race/Ethnicity
JAVIER	6	5	6	Bachelor's in Microbiology	Latino
CARLOS	3	2	5	Bachelor's in Biology	Latino

JOANNE	10	0	1	Bachelor's in Biology, some graduate work in Microbiology	White (non-Latino)

Table 4: Participants' personal data for pilot study #2.

Javier, a man in his late-twenties, had taught biology and integrated physics and chemistry at the study site for six years. Carlos, also in his twenties, was in an earlier stage of his teaching career. He had been teaching for three years and was in his second year of teaching biology. Javier's teaching career began at the study site and he had a genuine rapport with the students in his classes.

Javier and the other biology teachers (with the exception of Joanne) had common planning meetings built into their schedules. Javier mainly met with Carlos alone because they both taught biology to sophomores, were located in proximity to each other, and were at the same place within the biology curriculum. They met about once or twice a week and their meetings were usually short, with them spending a few minutes to briefly talk about where each was at within the biology curriculum, the overall lesson plan for the rest of the week, and which activities each planned to use for communicating the main points of upcoming lessons. Carlos and Javier had good working relationship with each other and Carlos saw Javier as a mentor. Many of the instructional activities and resources Carlos used were the direct result from Javier having used them in the past. They usually planned out their activities together and shared the same resources. At the time of data collection, Javier taught six general biology sections, with his classes consisting of 22-28 students. Carlos taught five general biology sections, of which two were Pre-AP classes, and his class sizes were a bit smaller than Javier's, averaging between 20-24 students.

Joanne is a woman in her fifties and was probably the most isolated teacher out of those who were teaching biology at the study site. Joanne is an experienced science teacher who has an undergraduate degree in biology and completed some graduate work in microbiology. She had taught for ten years, but had never taught a single course in biology. She was teaching one section of biology during this particular semester as a result of a scheduling mishap. All her other classes were physics sections. As a result, her schedule allowed her to partake in common planning with just the other teachers who were teaching physics as well. Her main person of contact for being kept up to date with what the other biology teachers were doing was the science department chair, who tried to stay informed about what each main science content area (biology, chemistry, physics) teaching group was doing. Her single general biology class had 19 students.

Pilot study #2 had many data sources, including teacher interviews, classroom observations, teacher content assessments, student artifacts, and student pre-/post-assessments. Data sources were numerous because attempting to "capture" how these teachers identified and addressed student alternative conceptions could have come at any point during the teachers' practices—from lesson planning to actual implementation to lesson reflection.

Methodology: Data Analysis

In order to answer the sub- research questions (#1-#3) stemming from the central research question (When teaching an instructional unit on evolution, how does a group of biology teachers identify and address their students' alternative conceptions?), the teachers' classroom practices and interview responses were analyzed and triangulated with the other data sources. Using a classroom observation instrument developed by Morrison and Lederman (2003), a tally was kept of the types of questioning strategies used by each teacher and the interactions that occurred between teacher and student(s). This observation instrument can be found in Appendix B. Samples of students' corrected written work were also analyzed for evidence of alternative conceptions.

The primary instrument that assessed teacher and student natural selection understanding was the widely-used and validated CINS (Anderson et al., 2002). The CINS consists of 20 closed-response (multiple choice) questions with a series of distracters derived from well-documented alternative conceptions and is designed to be completed in 30 minutes. Ten concepts (*biotic potential, population stability, limited (natural) resources, limited survival, variation within a population, origin of variation, variation is inherited, differential survival, change in population,* and *origin of species*) related to natural selection are represented on the CINS (2 questions per concept). All three teacher participants were assessed with a modified version of the CINS that was also administered to the students (n=96). This version of the CINS is found in Appendix C.

The modified version of the original CINS had specific vocabulary terms explained (e.g. iridescent=reflective) that might have posed difficulty to high school students and included illustrations of the animals from each CINS reading passage. Modifications on this version of the CINS were made in early 2011 from the feedback that was gathered when the original version of the CINS was administered to a group of approximately 15-20 volunteer high school juniors enrolled in a general chemistry class at the study site. The original version of the CINS had a Flesch-Kincaid grade level score of 9.7 (indicating an average ninth-tenth grader could understand its text) and a Flesch reading ease score (FRES) of 53, which was slightly beyond the upper limit of what an average 13- to 15-year-old student could easily understand. The modified CINS had a slightly lower Flesch-Kincaid grade level score (9.4) and higher FRES of 56, indicating text which was somewhat more "on par" with what an average ninth grader (in his/her second semester) could understand.

Sub-research question #2 was partly determined by the CINS as well. Each teacher used the CINS to predict what his/her students' most common alternative conceptions were and these predictions were compared to their students' actual performance on the CINS.

A detailed profile of each teacher and his/her classroom practice was then created. As each profile was developed, the multiple data sources were triangulated in order to identify patterns and construct explanations (Yin, 2003). Coding categories related to identifying and addressing student alternative conceptions provided a framework with which to describe the teachers' practices. The profiles were then used to compare and contrast each teacher in terms of topic-specific subject matter knowledge, strategies used for formative assessment, and individual interview responses.

Results for Research Question #1: What is the nature of these biology teachers' subject matter knowledge with regards to evolution and natural selection, specifically, and how does this knowledge inform their teaching practice?

The teachers' subject matter knowledge was initially assessed with their own personal answers on the CINS. Javier and Joanne answered 95% of the CINS questions correctly and Carlos answered 80% of the questions correctly. The teachers' subject matter knowledge was also described from how they answered various questions about their backgrounds and teaching. These descriptions included: 1) educational background and experiences with evolution; 2) attempts at integrating evolutionary concepts throughout different topics in biology; 3) acceptance of evolution; 4) prior experiences with teaching evolution; 5) goals and purposes of their evolutionary instruction; and 6) approaches to teaching evolution.

Personal educational experience with evolution. All three teachers had somewhat similar backgrounds with evolutionary biology. As an undergraduate biology major, Joanne had three or four courses in topics surrounding evolutionary biology and has fond memories of those courses, which might explain why she felt very much at ease teaching evolutionary concepts. During their undergraduate years as microbiology and biology majors, respectively, Javier and Carlos recalled having taken only one class on evolutionary biology, and as teachers, had thus far received no professional development on the teaching of evolution (as has Joanne). Carlos remembered his evolutionary biology course as being “very difficult”, but did not feel uncomfortable teaching evolution. Despite little formal educational experience with evolution, Javier felt quite comfortable teaching the topic as well, and all three teachers saw how evolution is the common thread that ties the discipline of biology together.

Attempting to integrate evolution with other biology topics. Viewing evolution as the underlying theme of biology leads to many opportunities for teachers to integrate evolution concepts throughout the curriculum. This thought was not lost with this group of teachers. According to Javier, he attempted to tie various concepts back to evolution whenever he could. Carlos attempted as well, but he, at times, admitted to holding back because he was concerned about confusing his students:

> I lose them more so when I start going into a lot of detail. I try to keep it very…basic, where instead of having to describe how this happened to this [unnamed species] and there [were]…obstacles, I just go, okay, well they [unnamed species] got here because of that…They [the students] don’t really care about how. (Pre-instruction interview, 3/9/11)

In the short time Joanne had been teaching biology, she was still getting accustomed to the array of biology topics in the curriculum, but she actually found herself discussing evolutionary concepts among her physics classes. However, she saw the pressure to teach so many topics in a short amount of time as a hindrance to possibly integrating evolution concepts more: “Really, I feel like there’s a lack of time. There’s so many places that it could be brought in and it’s just one of those things that ‘God…I wish I’d said that’” (Pre-instruction interview, 3/9/11).

Acceptance of evolution. All three teachers fully accepted evolution as a fact of science. However, upon closer examination, Carlos began to question himself a little more. He stated that his beliefs were a combination of evolution-acceptance and creationist:

> I kind of believe it’s kind of half [evolution] and half [creationism]…I’ll sum it up in one sentence: You can’t make something out of nothing. No matter how long it just sits there…If you get a glass of water and you heat it and kill everything in it, it’s not going to evolve something in there. There has to be something in there. Life had to have sparked from somewhere and that’s where I guess my creationism…now did He create humans in a day? No…evolution occurred, but I don’t…I’m kind of like, well, how did life start? There had to be something to spark it. (Pre-instruction interview, 3/9/11)

Prior experiences with teaching evolution. Encountering alternative conceptions from students was an occasional occurrence for all three teachers, especially with this topic. Javier stated that he had faced difficulties and challenges from students when teaching evolution in the past. Most of these challenges stemmed from students’ religious beliefs and Javier addressed these particular views in accordance with his epistemological stance. According to Javier:

> I mean, it’s not like I’m trying to put my opinion, it’s [evolution is] just a fact…I kind of show them like, whenever they [scientists] find things, it never disproves

> it. It always fills in more of the gaps…Most of the people accept it [evolution] as fact, but there's never been anything to, like, disprove it. (Pre-instruction interview, 3/8/11)

Carlos seldom found resistance among his students, but he believed many of his students simply were not vocalizing their views. Nevertheless, Carlos mentioned that some students will question his belief in God because he teaches science. To some of his students, accepting science meant turning away from God:

> I've had the question, "You don't believe in God and you believe in this [evolution]?" And I say, "I never said I didn't believe. I already told you my belief. There was something that had to have happened *(referring to his reconciled view)*." I kind of share that with them and they're like, "Well, I guess I can go with that." I would assume if you're just believing in evolution with no type of, you know, God complex or creationism, they have a hard time, you know, listening to you and saying, "Ah *(in a dismissive tone)*, he just…he doesn't know what he's talking about…He just believes in science". (Pre-instruction interview, 3/9/11)

With no prior experience teaching biology, Joanne did not have any memories from which she could recall. However, she imagined how she would address students with creationist viewpoints. She believed in a matter-of-fact approach and providing multiple examples of evolution's occurrence:

> You simply have to give them the facts. This is what we [scientists] see and give them [students] the examples, multiple examples…like the finches and the turtles and, you know, geographically isolated populations that changed…You always say that they're entitled to their opinions and their beliefs and if this is what they truly believe, then okay, I can respect that. However, this is the scientific side of it, and I need for them to know that this is what science and the real world say". (Pre-instruction interview, 3/9/11)

Goals and purposes of evolutionary instruction. Javier, Carlos, and Joanne were relatively clear about the goals and purposes of their individual evolution instruction. Javier identified his overarching goal for teaching evolution as emphasizing change over time. He added that he wanted his students to appreciate the rate at which events occurred and species just did not appear all of a sudden or because of "magic". Carlos believed his students needed to be familiar with the concept of natural selection, not just because it was a concept found on the state assessment, but because he wanted his students to talk intelligently about the topic. He felt the need to supply his students with as much information as possible about how evolution occurs so that they could decide for themselves whether they accept evolution or creationism. Finally, Joanne wanted her students to appreciate the evolution process, itself:

> I guess the most important thing is talking about how it happens. The idea that we have an attribute or a characteristic or a trait that makes us successful and that has kept that person or animal survive to reproduce and goes on. The ones that don't make the grade…they die. That's the thing I think they need to know most about evolution. (Pre-instruction interview, 3/9/11)

Like Carlos, she felt that if her students were knowledgeable about the topic, they could speak intelligently about it and get away from the common misconception that humans evolved from monkeys.

Approaches to teaching evolution. For these teachers, their individual instructional approaches to teaching evolution set the tone for the unit. When describing his quick-paced approach to teaching evolution, Javier said he tried to incorporate as many real-world examples as he could, such as discussing drug-resistant bacteria and viruses that are difficult to control. Nevertheless, Javier mentioned that he constantly felt the pressure of high-stakes testing and was always inclined to move on to other topics. As a result, he never spent as much time as he would have liked when teaching a particular topic, especially evolution. Even though Javier viewed the state-mandated test as a "curse", he also found ways to use it to his advantage. For example, when beginning his unit on evolution Javier traditionally encountered resistance in the form of students not wanting to believe evolution due to religious viewpoints. Seeing this as a barrier to potential understanding, Javier used the state-mandated test as the main reason why his students should understand evolutionary concepts: "I just tell them they have to know it [evolution] for the [state-mandated] test to graduate. So, I figure that's usually the only way. That's the only reason why they believe it or parts of it" (Pre-instruction interview, 3/8/11).

The state-mandated test dictated the specific topics Javier usually taught during the instructional unit and he designed his lessons around the concepts on which the students will be tested. He almost always began with a general overview of what evolution is and tried to engage his students in the topic by showing them visual images and short videos related to how evolution occurs. Javier then usually moved into discussing Charles Darwin and natural selection and the last topic he typically taught dealt with the evidence for evolution.

Carlos, like Javier, did not plan to allot a great deal of time to teaching evolution concepts. However, even with quick exposure to evolutionary concepts, Carlos still proceeded with caution because he knew some of his students felt a little uneasy about evolution. He stated that he usually began his instructional unit with an overview of what evolution is and he did so with the help of an animated video clip to which the students could relate. He tried to "read" how his students were handling the topic thus far and then transitioned to discussing Charles Darwin and natural selection, and ended the unit with the evidence for evolution. During the pre-instruction interview Carlos mentioned he had a strong affinity for hands-on activities and believed they help to enhance his students' understanding of science concepts in general, not just those that are specific for evolution. He did not incorporate many of these activities the previous time he taught evolution, and thought that their implementation could have made the difference between his students somewhat understanding evolutionary concepts and his students clearly understanding them. For guidance with what activities to use, with particular regard to natural selection, Carlos turned to Javier because he felt that whatever Javier was doing "obviously works".

At the time of the pre-instruction interview, Joanne did not have a chance to really think about how she approached her upcoming evolution unit, but she felt it was important for her students to be familiar with the vocabulary terms that were part of the unit. The fact that her students were studying genetics immediately before starting evolution put her somewhat at ease because she believed genetics was a natural "lead-in" to evolution, and then perhaps some of the evolution concepts would not be so difficult for her students to grasp. She had not thought about the sequencing of her evolution unit and was not quite sure how much time the unit would take; all of this depended on how much her students would have understood the material.

Results for Research Question #2: What is the nature of the biology teachers' knowledge of their students' alternative conceptions with regards to natural selection, specifically, and how does this knowledge inform their teaching practice?

All three teachers exhibited strong topic-specific content knowledge, but their knowledge in how their students would respond on the CINS was somewhat more inconsistent. The teachers were individually asked to predict their students' most common alternative conceptions for every single question, but they skipped some questions and chose multiple distracters for specific questions. Carlos made predictions on 13/20 (65%) of the questions, Javier made them on 16/20 (80%), and Joanne made predictions on all (20/20, 100%) questions. To review how each teacher predicted their students' alternative conceptions, see Table 5 below. The table also shows the natural selection concepts with which each teacher made predictions and lists the alternative conceptions each answer distracter was addressing.

Concept & Question	**# of students answering question**	**Answer choice**	**% of students with answer choice**	**Teacher predictions of student alternative conceptions**	**Alternative conception**
Biotic Potential					
#1	96	a	6%	Ja, Jo	Organisms only replace themselves.
		b	19%	C	Populations level off.
		c	57%		Correct answer
		d	18%	Jo	Populations level off.
#11	93	a	20%	Ja, Jo	Organisms only replace themselves.
		b	40%		Correct answer
		c	12%	Jo	Not all organisms can achieve exponential population growth.
		d	28%		Populations level off.
Natural Resources Are Limited					
#2	95	a	44%		Correct answer
		b	27%	Ja, Jo	Organisms can always obtain what they need to survive.
		c	17%	C, Jo	Organisms can always obtain what they need to survive.
		d	12%		Organisms can always obtain what they need to survive.

#14	93	a	16%	Jo	Organisms can always obtain what they need to survive.
		b	33%	C, Ja, Jo	Organisms can always obtain what they need to survive.
		c	20%	Jo	Organisms can always obtain what they need to survive.
		d	30%		Correct answer
Populations Are Stable					
#3	96	a	31%	Jo	All populations grow in size over time.
		b	43%		Correct answer
		c	16%		Populations always fluctuate widely/randomly.
		d	10%		Populations decrease.
#12	93	a	26%		Correct answer
		b	23%	Jo	All populations grow in size over time.
		c	28%		Populations decrease.
		d	24%		Populations always fluctuate widely/randomly.
Change in a Population					
#4	96	a	33%	Jo	Changes in a population occur through a gradual change in all members of a population.
		b	25%		Correct answer
		c	15%	Ja, Jo	Learned behaviors are inherited.
		d	27%	Jo	Mutations occur to meet the needs of the population.

#13	93	a	25%	C	Changes in a population occur through a gradual change in all members of a population.
		b	25%		Correct answer
		c	14%	C, Jo	Learned behaviors are inherited.
		d	37%	Ja, Jo	Mutations occur to meet the needs of the population.
Limited Survival					
#5	96	a	17%	Jo	Organisms work together (cooperate) and do not compete.
		b	25%	C, Jo	There's often physical fighting among one species (or among different species) and the strongest ones win.
		c	27%	Jo	Organisms work together (cooperate) and do not compete.
		d	31%		Correct answer
#15	93	a	16%	Jo	Organisms work together (cooperate) and do not compete.
		b	38%	C, Jo	There's often physical fighting among one species (or among different species) and the strongest ones win.
		c	23%		Mutations are adaptive responses to specific environmental agents.
		d	24%	Ja	Correct answer
Origin of Variation					
#6	96	a	33%	C, Ja, Jo	Mutations are intentional: an organism tries, needs, or wants to change genetically.
		b	15%		Correct answer
		c	24%		Mutations are adaptive responses to specific environmental agents.
		d	27%	Jo	Mutations are intentional: an organism tries, needs, or wants to change genetically.

#19	87	a	31%	Jo	Mutations are intentional: an organism tries, needs, or wants to change genetically.
		b	24%	Ja, Jo	Mutations are intentional: an organism tries, needs, or wants to change genetically.
		c	22%		Correct answer
		d	23%	C, Jo	Mutations are adaptive responses to specific environmental agents.
Inheritable Variation					
#7	96	a	10%	Ja, Jo	Traits acquired during an organism's lifetime will be inherited by offspring.
		b	20%		When a trait (organ) is no longer beneficial for survival, the offspring will not inherit the trait.
		c	41%		Correct answer
		d	29%	Jo	Traits that are positively influenced by the environment will be inherited by offspring.
#17	89	a	29%	Jo	Traits acquired during an organism's lifetime will be inherited by offspring.
		b	8%	C	When a trait (organ) is no longer beneficial for survival, the offspring will not inherit the trait.
		c	24%		Changes in a population occur through a gradual change in all members of a population.
		d	39%		Correct answer
Origin of Species					
#8	96	a	22%		Correct answer
		b	2%		Speciation is a hypothetical idea.
		c	50%	C, Ja, Jo	Organisms can intentionally become new species over time (an organism tries, wants, or needs to become a new species).
		d	26%	C, Jo	Organisms can intentionally become new species over time (an organism tries, wants, or needs to become a new species).

#20	86	a	28%	C, Jo	Organisms can intentionally become new species over time (an organism tries, wants, or needs to become a new species).
		b	19%		Correct answer
		c	16%		Speciation is a hypothetical idea.
		d	37%	C, Ja, Jo	Organisms can intentionally become new species over time (an organism tries, wants, or needs to become a new species).
Variation Within a Population					
#9	94	a	10%	Ja, Jo	All members of a population are nearly identical.
		b	25%		Variations only affect outward appearance, don't influence survival.
		c	29%		Variations only affect outward appearance, don't influence survival.
		d	37%	Jo	Correct answer
#16	91	a	20%	Jo	All members of a population are nearly identical.
		b	14%	Ja, Jo	Variations only affect outward appearance, don't influence survival.
		c	56%		Correct answer
		d	10%		Organisms in a population share no characteristics with others.
Differential Survival					
#10	94	a	42%	C, Ja, Jo	Fitness is equated with strength, speed, intelligence or longevity.
		b	24%	Jo	Fitness is equated with strength, speed, intelligence or longevity.
		c	18%		Correct answer
		d	16%	C	Organisms with many mates are biologically fit.

#18	87	a	31%	C, Ja, Jo	Fitness is equated with strength, speed, intelligence or longevity.
		b	18%		Correct answer
		c	17%		Fitness is equated with strength, speed, intelligence or longevity.
		d	33%	Jo	Fitness is equated with strength, speed, intelligence or longevity.

Table 5: Frequency of student responses on CINS pre-assessment and alternative conceptions predicted by Carlos (C), Javier (Ja), and Joanne (Jo) in pilot study #2.

Javier made a prediction on each topic (may not have been for both questions on each topic), with the exception of *populations are stable*. In a similar manner, Carlos made some sort of prediction (predicting on either one or both questions on each concept) on all topics, with the exception of *populations are stable* and *variation within a population*. For the most part, Carlos made single predictions for each question on which he made a prediction (9/13, 69%), whereas Javier made single predictions exclusively (16/16, 100%). Joanne was on the opposite end of the spectrum, with almost exclusively making multiple predictions for each question. As stated before, Joanne made predictions on every question, and almost all (18/20, 90%) had multiple predictions. The only concept on which she made singular predictions was *populations are stable*.

When making singular predictions, both Carlos (4/9) and Javier (7/16) were accurate 44% of the time and Joanne (2/3) was accurate 67% of the time. When making two predictions for a particular question, Carlos (2/4) was accurate 50% of the time and Joanne (7/13) was accurate 54% of the time. Measuring accuracy with Carlos and Joanne was made more difficult due to their nature of making multiple predictions. In addition, Joanne's accuracy was particularly challenging to measure because of the small number of students' scores (n=5) that were authorized to be used for this study. As a consequence, her results were inconclusive.

Two natural selection concepts (*origin of species* and *differential survival*) had instances where all three teachers were consistent in their predictions and these predictions were quite accurate with how their students performed (see Table 5). All other topics demonstrated varying amounts of inconsistency with predictions and student outcomes.

Teachers' knowledge of students' conceptual difficulties. All three teachers discussed the conceptual difficulties of students they had encountered in the past or think they would have encountered during the instructional unit, and most of what the teachers mentioned revolved around the global concept of *deep time.* Javier believed his students in the past had a difficult time conceptualizing *deep time*: "In fact, students, like, mention about the black hole consuming us in a couple billion years and they lose sleep over it. But, they don't realize, like, how long a billion years is" (Pre-instruction interview, 3/8/11). Nevertheless, despite trying to explain this concept further, he felt the concept was and will continue to be lost on his students. Again, even though Joanne had never taught evolution, she made a worthy attempt at predicting how her students might also fail to appreciate *deep time:* "That, I think it's gonna be…that sequence is going to be the hardest for them to understand…" (Pre-instruction interview, 3/9/11). Carlos echoed the idea of his students not understanding the amount of time involved in evolution as well:

> They [the students] have a hard time understanding…that evolution is over time…Let's say one finch just developed this large beak instead of…several beaks. [They do not understand] there was a…lineage of increasingly large and larger and larger beaks…They think it's just an overnight…that one finch was born with this big beak and that's the way it goes (Pre-instruction interview, 3/9/11).

Moreover, Carlos mentioned his students also had a difficult time understanding that *learned* behavior is not necessarily a genetic trait and these behaviors, such as being frugal with money or having little patience, are not passed down to succeeding generations.

Formative assessment strategies. The main methods of formative assessment used by each teacher were informal questioning and reviewing student work. There were more subtle strategies as well, such as reading students' visual cues and body language. However, it was unclear how gathering this information about their students' knowledge was truly impacting their lessons. For the most part, as long as each teacher saw that most of their students were "keeping up", there was no need to adjust. But, if any of the teachers saw that an entire class was having trouble completing an activity, a different instructional strategy was used. Based on pilot study #2's observations, this readjustment occurred once with Joanne's class. She turned one of her student activities into a series of whole-class demonstrations on Day 2 of instruction because she believed the activity was too complex for her students to complete on their own. In general, the teachers valued their methods of formative assessment, but felt that by the time they absorbed the information their students were giving them, it was too late in their instructional sequence to go back and address the problems. As a result, the teachers' formative assessments were not necessarily formative at all because their instruction was not affected.

Strategies to identify alternative conceptions. None of the teachers used any type of formal instrument to identify students' alternative conceptions prior to or after each lesson. There was no evidence of pre-testing (other than the research-implemented CINS), interviewing, concept mapping, exit slips, or using writing prompts during classroom observations.

Overall, each teacher's instructional strategy for the entire evolution unit consisted of condensing subject matter into concepts that were represented on the state assessment. For example, Javier introduced fundamental evolution concepts to his students on Day 1 in the form of a Power Point presentation. The concepts were: *evolution, natural selection, homologous structures, analogous structures, fossil,* and *speciation.* All of these terms were sure to be included on the state assessment. However, before providing any sort of explanation with these concepts, Javier gauged his students' prior understanding of these terms by asking many recall questions of his students. For example, before explaining *fossil*, Javier asked his students, "Is a fossil a bone?" When presented with concepts such as these, Javier's students described the concepts in their own words, ranked their knowledge of the concepts on a scale from 1 to 4, and drew simple sketches that helped them remember the concepts. They completed these tasks on a separate handout that got turned in to Javier as part of an assignment. Javier believed in the "power" alternative conceptions may possess, in that they could be viewed as learning opportunities, but simply felt that he did not have the time to identify or address all of them:

> If I feel that the misconception might be something that a lot of them have, then I want to talk about it more…I mean, the right answer is always nice, but I guess the right answer isn't always the best answer. I want just…I want them to think more…Just because it's [the student response] from left field, I don't think it's like wrong, wrong. It might be kind of right and not totally wrong…it's still worth talking about even though it's from left field…if I have the time. (Post-instruction interview, 4/1/11)

Carlos's strategy depended heavily on informal whole-group questioning before an instructional activity took place, students verbalizing questions they had about the content, and looking over student work. However, by the time Carlos gathered information on whatever alternative conceptions his students had, most of his instructional lesson had already taken place and he had to find a later time to address the alternative conception:

> …When I find that out, it's usually too late. I'm already in the middle of a lesson and at that point, I try to have a…bell-ringer (sample question from state assessment) or something over the past topic…they're struggling with so that…it can just be…a refresher…so that maybe I can correct any misconceptions…(Pre-instruction interview, 3/9/11)

Joanne's strategy for identifying alternative conceptions certainly included informal student questioning and checking student work, but she also depended on visual cues supplied by her students to verify student understanding. Since large portions of her lessons depended on teacher-centered classroom discussions with recall-type and open-ended questions, students' visual cues were very important to her:

> I tend to find myself doing that [checking visual cues] with my students…the students' faces, many times, tell me, "OK, do I need to continue in this vein? Do I need to move on? Do we need to step it up? Do we need to calm down? Do we need to amp it up?" (Post-instruction interview, 4/1/11)

Student work checked by all three teachers during the evolution unit yielded no recognition of student alternative conceptions. Javier and Joanne graded student work and gave it back to students, but Carlos did not, for fear that his students who turn in late work would copy another student's assignment. None of the teachers wrote any specific comments on students' assignments during grading that showed evidence of the teachers' recognition of an alternative conception.

Student alternative conceptions not addressed by teachers. Some of the questions and activities used by each teacher were viewed as ways to uncover students' alternative conceptions, but some alternative conceptions went unrecognized by the teachers. For example, when Javier had his students compose their own definitions and sketches for different evolution terms, such as *natural selection*, many of his students used this opportunity to write and draw “everyday” definitions of the terms. An analysis of the student artifacts for this assignment (in particular for the term *natural selection*) found that many students wrote “survival of the strongest” as their definition and drew weightlifting barbells as a way to remember *natural selection*. Confusing the biological definition of *fitness* with its everyday definition of “strength” or “exercise” is a common alternative conception, and this occurrence was not noticed by Javier. Carlos had a similar experience with the concept of *fitness*. However, after trying to further explain the biological definition, Carlos resumed the everyday usage of the term and allowed his students to use *fitness’s* everyday definition as well. As mentioned previously, Joanne’s main mode of discourse was through teacher-centered whole class questioning. Many of Joanne’s questions to her students during the evolution unit may have been designed to elicit students’ ideas, but when she would not receive a particular answer from her students, she would sometimes supply it herself. In addition, many of the same students would tend to answer her questions. So, whether or not she recognized her students’ alternative conceptions remains unclear.

All three teachers relied on student questioning to elicit student ideas and many students observed during each teacher’s unit offered wrong answers, but all three “filtered” through the wrong responses until the correct answer was heard a student or supplied by him/herself. The rationale for choosing not to probe more deeply was the pressure to maintain a timeline of scheduled instructional activities and move on in order to get through more material. Therefore, all three teachers may recognize the answers given by their students as alternative conceptions, whether they may be beneficial or problematic, but choose to ignore them due to time constraints.

Results for Research Question #3: At the conclusion of the evolution instructional unit do the biology teachers' respective students maintain or modify their alternative conceptions regarding natural selection?

Student answers on the CINS yielded interesting results. Table 6 lists the percentage of total students who answered specific natural selection concepts correctly. The percentages are in order from greatest to least, indicating which concepts were more understood and which posed more difficulty. For example, on the pre- and post-assessments, most students had the least amount of difficulty with the concepts of *biotic potential* and *variation within a population* (see Table 6). On the other hand, *origin of variation* and *differential survival* posed most difficulty for the students.

Student Results (By Concept)—Pre-Test N=86-96		**Student Results (By Concept)—Post-Test N=85-93**	
Concepts	% Correct Responses	Concepts	% Correct Responses
Biotic Potential	49%	Biotic Potential	53%
Variation Within a Population	47%	Variation Within a Population	49%
Inheritable Variation	40%	Inheritable Variation	45%
Populations Are Stable	34%	Populations Are Stable	44%
Natural Resources Are Limited	37%	Natural Resources Are Limited	40%
Limited Survival	28%	Limited Survival	37%
Change in a Population	25%	Change in a Population	28%
Origin of Species	20%	Origin of Species	28%
Origin of Variation	19%	Origin of Variation	21%

Differential Survival	18%	Differential Survival	21%

Table 6: Comparison of student pre-/post-assessment CINS results arranged by concept.

One of the focal points of the instructional unit (at least for Javier and Carlos) was an activity entitled "Variation in a Population", and given that at least one class meeting was dedicated to this activity, it is not surprising that the concept of *variation within a population* had a higher percentage of correct answers with this group of students as opposed to other concepts. This concept and the concept of *inheritable variation* are strong genetics concepts which are heavily emphasized throughout elementary and middle school science. In addition, this group of students had just completed a lengthy genetics unit, so there was little doubt that these related concepts were still fresh in their minds. This occurrence, coupled with prior knowledge on genetics, might explain student performance on these related concepts.

However, the other related concept, *origin of variation*, remained difficult for students to understand. *Origin of variation* posits that "random mutations and sexual reproduction produce variations" and "while many are harmful or of no consequence, a few are beneficial in some environments" (Anderson et al., 2002, p. 965). As with more abstract concepts which require a fundamental understanding of basic related concepts, *origin of variation* is no different. Because the alternative conceptions surrounding this concept (i.e. traits arising in response to need; the types of new traits that occur are determined by the environment) are innately attractive (Gould, 1980), it is imperative to have a solid understanding of inheritable variation within a population. Although the students did not have robust knowledge of these concepts (the pre-test averages of those who answered correctly were 47% [*variation within a population*] and 40% [*inheritable variation*]), there was still a good deal of prior knowledge on which to build.

The concept of *differential survival* also posed difficulty to these teachers' students. *Differential survival* is related to the biological concept of fitness, in that "those individuals whose surviving characteristics fit them best to their environment are likely to leave more offspring than less fit individuals" (Anderson et al., 2002, p. 964). The most common alternative conceptions associated with this concept are equating fitness with strength or speed. Throughout the research study, the teacher participants did not choose specific activities directly focused on this concept, but *fitness* did appear during teacher questioning and explanations; however, despite the teachers' attempts at emphasizing the correct interpretation of *biological fitness,* students still held alternative conceptions, perhaps reinforced by inconsistency of term usage. A scene from one Javier's classes illustrates this point. As previously described, in an assignment from Day 1 of instruction, Javier's students must explain a term in their own words and draw a picture to help them understand and remember the term. One of the terms was *natural selection*:

> Javier asks his students, "Natural selection is survival of the what?" Various students answer, "fittest." A student asks Javier to repeat, "Survival of the what?" Javier answers, "Fittest…or strongest, but preferably fittest." The same student asks, "Can I just draw a picture of a muscle?" Javier answers, "That's fine". (Classroom observation, 3/21/11)

Discussion

Overall, pilot study #2 yielded expected, yet nuanced results, and it certainly had implications for the execution of the current dissertation study. Pilot study #2's first major finding was that other than checking written student assignments, none of the teachers had any formal strategy (i.e., pre-test, exit slips, concept mapping) in place to identify their students' alternative conceptions. Rather, the teachers relied on (when available) their historical knowledge of previously teaching evolution to realize what the major alternative conceptions were on the topic. However, according to informal lesson plans and classroom observations, lessons were not structured around the alternative conceptions with which the teachers were familiar and all three teachers used the same sorts of instructional activities as the principal means to carry out learning objectives. The teachers' knowledge of alternative conceptions, in a sense, was only used if and when the alternative conception(s) became apparent. In addition, there were occurrences where alternative conceptions were not recognized and this was most likely because a particular teacher did not perceive them to be alternative conceptions in the first place. These teachers relied heavily on informal, recall-based questioning as their form of assessment, and did not use the information gathered from such questioning to modify their lessons in a significant way, such as altering an instructional activity to include a question that addressed an alternative conception.

The second major finding from this study was that while these teachers demonstrated strong content knowledge, accepted evolution as a scientific fact, and were knowledgeable about global evolutionary alternative conceptions, they were not necessarily knowledgeable about the specific alternative conceptions their students had with regards to natural selection. The teachers were somewhat inconsistent (with each other and their students) when asked to predict what their students' most common natural selection alternative conceptions were on the CINS (Lucero & Petrosino, 2012).

Pilot study #2's second major finding led into the next line of this research inquiry. All three teachers from pilot study #2 used the CINS to predict their students' alternative conceptions, but the possible relationship between the teachers' SMK and their prediction accuracy (i.e., PCK area of *knowledge of students' alternative conceptions*—see Figure 5) was never investigated. Moreover, the teachers' orientation to science teaching, that is, what they believed the importance was of being familiar with and identifying alternative conceptions, was also never explored. If this information is known, it may provide more insight into the teachers' pedagogical content knowledge for the topic of evolution, with particular regard to the knowledge of their students' ideas/areas of difficulty and orientation to science teaching as a whole. In addition, learning more from investigating this relationship between teachers' perceptions and actual classroom implementation has implications for how evolution is taught by biology teachers at all levels of expertise.

Finally, the conceptual inventory itself played a major role in this pilot study, and its utility as both a diagnostic and formative assessment tool remained unexplored at the secondary level. During pilot study #2, the students answered questions on the conceptual inventory before formal evolution instruction began, but these results were never relayed back to the teachers. As a result, the question remains of what the teachers would have done with this information had it been given to them. Thus far, a few biology conceptual inventories have been developed for use at the undergraduate level (see Klymkowsky & Garvin-Doxas, 2008; Smith, Wood, & Knight, 2008; Bowling et al., 2008), but their usefulness and adaptability at the secondary level remains unexplored.

Problem Statement

The subsequent chapters report the methodology, results, and implications of the current (third) study. Drawing on the findings from pilot studies #1 and #2, the overall goal of the current research was to further examine how the study site's biology teachers' awareness of their students' evolutionary and natural selection alternative conceptions influenced aspects of their teaching practices—from lesson planning and implementation to reflection. The current study was designed to maintain the extended continuity of the two previous pilot studies by involving four new teacher participants (100% of the biology teachers at the study site) and a larger sample of each teacher's students from the same study site. The study also aimed to closely examine each teacher's views on the teaching of science and evolution and how these views related to their individual practices. Finally, the study intended to investigate how each teacher used the student results from a pre-test administration of the CINS within the context of his/her practice. For review, the current research study's specific research questions are listed in Chapter 1.

Teachers' familiarity with their students' prior knowledge and alternative conceptions is a powerful resource when teaching any topic. When the topic is evolution, this knowledge becomes even more valuable, especially since evolution is such a misunderstood topic. During pilot study #1, student prior knowledge was probed to some extent at the beginning of the instructional intervention, but it did not fully shape and mold subsequent lessons. Based on the results from pilot study #1, the implementation of the intervention may have oversimplified and underestimated the complexity of the students' learning processes. This result is consistent with similar statements in that the students' actual knowledge structures are "multifaceted, highly responsive to idiosyncratic aspects of context, and somewhat fluid" (Taber, 2001, p. 168). Having a more comprehensive awareness of students' ideas could have potentially informed the intervention. If at hand and resourceful with this knowledge about students, a teacher can make long strides at facilitating student understanding of the abstract concepts that typically characterize evolution. The intriguing question here is if teachers are provided with such information about student knowledge, how will they use it? Or, will they even use it? The familiarity of this student knowledge and its usefulness can reveal insight into a teacher's pedagogical content knowledge for this topic.

Teachers' SMK of evolution may also potentially inform their PCK. Pilot study #2 began to outline the possibility of this relationship by having teachers answer questions (as a measure of SMK) and predict student responses on the CINS (as a measure of PCK). Teachers' knowledge and awareness of students' conceptions (an element of a teacher's PCK) have been investigated in the realms of physics (e.g., Berg & Brouwer, 1991) and genetics (Gottheiner & Siegel, 2012), but research within evolution and natural selection is relatively scarce. However, this pilot's procedure for determining the teachers' "prediction accuracy" was rather undeveloped and it became apparent that a clearer procedure needed to be in place, especially one that attempted to take into account a teacher's option for making either single or multiple predictions on a specific question. Furthermore, it is important to determine if the teachers' SMK is separate and distinct or directly related to their PCK, with regards to their awareness of student ideas/areas of student difficulty. This determination can be observed by measuring the prediction accuracy of the questions the teachers personally answer correctly or incorrectly on the CINS. If the teachers' prediction accuracy remains relatively high for both correctly- and incorrectly-answered questions, then this indicates that SMK and PCK are distinct for the topic of evolution. This preliminary determination may provide grounds for further study that can have potential policy implications, especially with some teacher education programs emphasizing a need in having teacher candidates possess substantial SMK over PCK.

Investigating the aforementioned SMK-PCK possible relationship through the use of a popular concept inventory, like the CINS, at the secondary level is necessary, especially for evolution. Pilot study #1 did not use an instrument like the CINS to assess students before the instructional intervention began, but the study may have benefitted from its use by providing "a window" into how the students thought of an array of natural selection concepts. Pilot study #2 began an implementation of the CINS, but that group of teachers never received the opportunity to either use the student information gathered from it or voice their opinions on its use as an alternate form of assessment. Many state assessments offer little useful information on true conceptual understanding of major topics like evolution and secondary science teachers often crave tools and instruments that can relay such important information. Understanding how a popular conceptual inventory is used (or not) by a typical group of biology teachers can have real implications for both researchers and practitioners.

Chapter Five: Methodology

This current line of inquiry was characterized as a mixed-methods study (due to the utilization of statistical methods to analyze student and teacher outcomes and validity of the CINS), and employed a qualitative exploratory case study approach, which is informed by the constructivist perspective of science education research. The constructivist perspective is useful for relaying the distinct knowledge and experiences an individual possesses and determining how that individual makes sense of his/her own personal experience in order to construct an understanding of the world around him/her (Stake, 1995). As set forth by this perspective, knowledge is a construction created (as opposed to knowledge that is discovered) by both the study participant and researcher (Stake, 1995; Crotty, 2003). Therefore, the knowledge and experiences of each individual were deemed to be unique constructs.

Teachers bring with them a set of individual beliefs about science teaching and learning that are constructed by past experiences as learners themselves and/or with students they have taught or are teaching. These beliefs continue to be shaped and molded and ultimately influence a teacher's practice, by affecting instructional decisions and actions in the classroom (Magnusson et al., 1999). Therefore, the teacher participants in this research study were observed constructing their knowledge of teaching through the lens of their classroom actions and experiences.

Context and Participants

School setting. This research study took place at Tobin H.S. (a pseudonym)—the same study site as pilot studies #1 and #2. Since Tobin had participated in the previous pilot studies, it made sense to continue with its participation for the current study. Doing so would provide a sense of overall cohesion to this extended line of research inquiry. Therefore, Tobin H.S. was chosen purposefully. Furthermore, I, as the primary researcher, personally knew key personnel at Tobin and the nature of my established relationships with these individuals made conducting research at Tobin a seamless process. Lastly, Tobin was not accustomed to educational research being conducted on its premises. Its status of being relatively under-researched made Tobin a logical setting to continue this line of inquiry of how evolutionary instruction was taking place and could add a valuable contribution to the research base.

Tobin H.S. is a diverse, urban school in west Texas with approximately 1700 students. It serves grades 9-12 and is located within a large, predominantly (81%) Latino community. The community within which Tobin is located had a median household income of $39,000 and a median home value of $114,000. There was an average of 3.01 individuals per household, with approximately of 23% of the community's population living below the poverty line. Approximately 22% of the community's population had attained a Bachelor's degree or higher and 25% of those individuals 25 years or older have never earned a high school diploma or GED.

At the time of data collection, about 90% of Tobin's student population was of Latino origin (compared with state average of 50%), 69% were classified as at-risk (state average = 45%), 14% were limited English-proficient (state average = 17%), and 87% were economically disadvantaged (state average = 60%). In 2011, the state education agency rated the campus as "academically acceptable", and was among three high schools in the district that failed to meet the U.S. government's Adequate Yearly Progress (AYP) standard due to inadequate math performance on the state assessment. Moreover, since Tobin failed to meet AYP standards for two years in a row (for the same reason, i.e. inadequate math performance), the high school was placed “on notice” by the state and was in the midst of a “school improvement plan” to increase its student math performance. After data collection took place for the current study, results for 2012 indicated that Tobin missed the AYP standards once more--this time, due to inadequate reading and math performance on the state assessment. Tobin is now developing a school improvement plan to address both reading and math student performance.

Again, after data collection and in August 2012 Tobin was designated by Texas’s education agency as a “STEM academy” for the 2012-2013 academic year. With this designation, Tobin is one of several dozen “rigorous secondary schools focusing on improving instruction and academic performance in science and mathematics-related subjects and increasing the number of students who study and enter STEM careers” (Texas Education Agency, 2011). According to the state agency, these STEM academies are demonstration schools and learning labs that develop innovative methods to improve science and mathematics instruction.

Tobin began implementing common planning among its four core academic areas (i.e., English/Language Arts, Social Studies, Math, and Science) in 2006 so that teachers could formalize lesson plans while sharing instructional resources and strategies. Back then, common planning time was built into these teachers’ schedules (e.g., the entire science department had its 2nd period designated as common planning meeting time) and 45 minutes of meeting time was required of the academic groups at least twice a week. This mandate was carried through until at least 2010 when Tobin’s administration was undergoing transition. Among other changes that occurred with Tobin’s leadership was a transition from a 4-class, 1½-hour daily block to a traditional 8-class, 45-minute daily schedule in 2011. At the time of data collection, Tobin’s administrators and science department chair/instructional coach no longer mandated that teachers turn in formal lesson plans nor meet with one another during common planning, but meeting was strongly encouraged at least two times a week. One meeting each week was set aside for larger department meetings, but the frequency of occurrence for these meetings was rare due to the science chair/coach being often called away for other administrative tasks and meetings.

Teacher participants. The participants in this study were the four teachers who all taught biology to >95% of Tobin's freshmen (ninth graders). All four teachers had varying amounts of experience. Participants are referred to by the pseudonyms Teachers A, B, C, and D. Personal participant data is found in Table 7.

TEACHER	YRS. OF BIOLOGY TEACHING EXPERIENCE	EDUCATION	NUMBER OF BIOLOGY CLASSES TEACHING	NUMBER OF BIOLOGY STUDENTS	RACE/ ETHNICITY
TEACHER A	7	B.S. IN ZOOLOGY	6	94	WHITE (NON-LATINA)
TEACHER B	3	B.S. IN BIOLOGY AND LAND SURVEYING	5	81	LATINA
TEACHER C	2	B.A. IN CHEMISTRY, B.S. IN BIOLOGY & BIOCHEMISTRY, COMPLETING GRADUATE WORK IN EDUCATION	5	82	LATINO
TEACHER D	1 semester	B.S. IN BIOLOGY	6	82	WHITE (NON-LATINA)

Table 7: Teacher participant personal data.

All four biology teachers were part of a larger department of 14 teachers and a department chair/instructional coach (herself a former Tobin science teacher) who taught no assigned classes. Each science sub-group had common planning meetings built into their daily 8-period class schedules. For example, all teachers who mostly taught biology classes received 3rd period as a designated meeting time. All teachers who mostly taught chemistry were designated to meet during 5th period and so forth.

Common planning meetings never had a predetermined structure of topics for the teachers to discuss. Attendance was never taken nor was there any formal record of what was discussed. However, there were several instances where the teachers' common planning was designated specifically for the teachers to partake in short campus/district-mandated trainings and data mining through district benchmark tests. Official common planning meeting time for biology teachers was scheduled for every Tuesday. Teachers A, B, and D all made a concerted effort to officially meet once a week, with Teachers A and D informally meeting almost every day. Teacher C made a conscious decision to not participate in common planning with his three colleagues, stating that his time was better spent on other teaching-related tasks.

Teachers A, B, and D all had a good working relationship with one another and saw each other as a valued resource in their professional lives. Teachers A and B, women in their early-mid forties, both had taught biology at Tobin for approximately three years. Teacher A had taught elsewhere in the U.S. due to traveling and moving with her military spouse, whereas Teacher B began her teaching career at Tobin. Teachers A and B began their tenure at Tobin the same year, were located in close proximity (directly across the hall), and had a genuine rapport with each other. Teacher D, a novice in her mid-twenties, had no prior experience teaching and was located upstairs from Teachers A and B. These three teachers' classrooms were located in a different building on Tobin's campus, away from the official science wing. Teachers A and B's classrooms were designed for laboratory use and were equipped as such, with counter/peninsular lab table space and water faucets with sinks. However, Teacher D's classroom was located in the social studies wing (her classroom was a converted social studies room with stand-alone, movable lab tables, but no water faucets or sinks). From the beginning of Teacher D's tenure at Tobin, Teacher A became a *de facto* mentor to Teacher D and these two teachers met almost every day to informally discuss the day's upcoming events or what had transpired during the first two class meetings of the day. In general, Teachers A, B, and D depended upon one another for a variety of purposes, from sharing resources and materials to covering each other's classes during last-minute appointments, meetings or personal emergencies.

For the most part, these three teachers constantly kept one another informed about upcoming lessons and their sequencing. Teachers A and D kept their instruction in synchronization with one another with regards to time spent teaching different concepts and topics. They were always within the same 1-2 days of the biology curriculum. Teacher B was usually slightly behind Teachers A and D by several more days. Each teacher had one Pre-AP Biology class and all three teachers taught biology throughout the day, with the exception of Teacher B, who as assistant swimming coach, was required to be with the school's swim team during the last period of the day. All three teachers had an average of 19-20 students in their biology classes.

Teacher C, a teacher in his early-thirties from a family of educators, was the only biology teacher who taught most of the Pre-AP Biology classes (n=3) in addition to his other biology classes. Teacher C had an average of 18 students in his biology (regular and Pre-AP) classes. He also taught one chemistry class. He had been teaching for five years and taught biology for two of those five years. Teacher C's classroom was located in the main science wing at Tobin and rarely interacted with his fellow biology teachers. He, for the most part, was never in the same place in the biology curriculum as his three biology colleagues. Whereas Teachers A, B, and D all tried to keep a similar time frame for teaching different instructional units, Teacher C was usually weeks behind his colleagues, much to the chagrin of the science department chair/instructional coach, who found Teacher C a challenging person with whom to work. She often became frustrated with different aspects of his teaching practice, from his refusal to attend common planning meetings to his implementation of lesson ideas that, in her opinion, resulted in minimal student learning. At the time of data collection, Teacher C was completing graduate work at the local state university as an instructional specialist in science. Many of the instructional activities and resources Teacher C used were the direct result from his graduate work and having used the same activities in the past.

Beginning approximately four to six weeks before each teacher's instructional unit on evolution, the principal researcher maintained a constant presence in all four teachers' classrooms as a non-participant observer. This was done in order to better understand the different classroom contexts with regards to overall teaching style, daily routines, typical instructional strategies, and relationship dynamics among students and their respective teacher. In addition, prolonged exposure to these teachers' practices provided a more accurate sense of the overall school setting, thereby better understanding the constraints that had an effect on the teachers' decisions and those with which the teachers had to work. This continuous engagement within these classrooms allowed for rich, thick descriptions of the teachers' practices, which could potentially transfer readers to a setting with which they could identify or find familiarity (Merriam, 1998).

Data Sources

The current study used a variety of data sources from a data corpus (see Table 8) that included observations of the aforementioned four high school biology teachers in their classrooms during their evolutionary instructional units and common planning meetings; interviews with these teachers regarding their personal perspectives on evolution, science teaching, and student knowledge; their classroom strategies for teaching evolution; and the teachers' and students' scores on the CINS. The timeline for the collection of these data sources is summarized in Table 9. The rationale for the study's data sources is explained below.

Data Source	Used in Current Study?
Teacher PCK interviews	Yes
Student CINS pre-/post-test results	Yes
Teacher pre-/post-instruction interviews	Yes
Common planning observations	Yes
Classroom observations during instructional unit	Yes
Classroom video—all teachers' biology classes during instructional unit Teacher A: 6 classes for 9 days Teacher B: 5 classes for 10 days Teacher C: 5 classes for 10 days Teacher D: 6 classes for 10 days	Yes (only classes formally observed by principal researcher—see Table 9)
Selected student artifacts	No
Teacher daily interviews	Yes

Table 8: Data corpus and sources used for current study.

	Week 1 2/20/12-2/24/12	**Week 2 2/27/12-3/2/12**	**Week 3 3/5/12-3/9/12**	**Week 4 3/19/12-3/23/12**	**Week 5: 3/26/12-3/30/12**	**Week 6: 4/2/12-4/6/12**	**Week 7: 4/9/12-4/13/12**	**Week 8: 4/23/12-4/27/12**
Teacher PCK Interviews	Teacher A: 2/24 Teacher D: 2/23	Teacher B: 2/29, 3/2 Teacher C: 2/29, 3/1		Teacher C: 3/20	Teacher C: 3/26			
Student CINS Pre-Test		Teacher A: 2/27 Teacher D: 2/27	Teacher B: 3/9	Teacher C: 3/23				
Teacher Pre-Instruction Interviews			Teacher A: 3/9 Teacher D: 3/9	Teacher B: 3/20	Teacher C: 3/27			

Common Planning Observations				3/19-3/20; 3/23		4/2-4/3		
Classroom Observations & Video (by class period) **Tchr A: 8th** **Tchr B: 7th** **Tchr C: 6th** **Tchr D: 5th**				Teacher A: 3/20-3/21; 3/23 Teacher D: 3/19-3/21; 3/23	Teacher A: 3/26-3/30 Teacher B: 3/26-3/30 Teacher C: 3/28-3/30 Teacher D: 3/28-3/30	Teacher A: 4/2 Teacher B & Teacher C: 4/2-4/5 Teacher D: 4/2-4/4	Teacher B: 4/10 Teacher C: 4/9-4/11	
Teacher Daily Interviews				Teacher A: 3/20-3/21; 3/23 Teacher D: 3/19-3/21; 3/23	Teacher A: 3/28-3/30 Teacher B & Teacher C: 3/28-3/30 Teacher D: 3/28-3/30	Teacher A: 4/2 Teacher B: 4/2-4/5 Teacher C: 4/3 Teacher D: 4/2-4/4	Teacher B: 4/10 Teacher C: 4/9, 4/11	
Student CINS Post-Test						Teacher A & Teacher D: 4/5	Teacher B: 4/11 Teacher C: 4/13	
Teacher Post-Instruction Interviews								Teacher A & Teacher B: 4/25 Teacher C: 4/27 Teacher D: 4/23

Table 9: Process and timeline for current study's data collection.

Teachers' topic-specific content knowledge and predictions of students' alternative conceptions (PCK interview). First, in order to evaluate whether or not the teachers' topic-specific content knowledge was a factor in instructional decisions, their content knowledge on natural selection was individually assessed before (approximately one week) their formal instructional unit on evolution began. All four teacher participants and their students (see section below on "Student Outcomes") were assessed with the modified version of the CINS that had been previously used in pilot study #2. Again, this version of the CINS is found in Appendix C. Teachers A, B, and D all were individually assessed at separate, distinct times in one sitting. Teacher C was assessed in a series of sessions over a period of several days due to multiple interruptions that interfered with his attention and focus on the CINS.

While the teachers were being assessed on the CINS, they were asked to annotate on their hard copy of the CINS which distracters their students were most likely to answer. They were also asked to explain their rationale for choosing those distracters. This was done to determine the consistency with which the teachers could predict the natural selection alternative conceptions their respective students held and whether or not their predictions were accurate. The explanation of rationale was done in an individual, alone think-aloud format, where each teacher was free to verbally explain his/her reasoning. This task was accomplished in the presence of the principal researcher so that she might ask follow-up or clarification questions, if necessary. This entire task (from assessment and prediction to explanation of rationale) was audio recorded.

The emotional climate during this entire task varied with each teacher. All teachers expressed some degree of apprehension at completing the CINS, and one of the teachers consistently second-guessed his/her initial answers. The teachers were more comfortable with making predictions for their students, but even in this setting, there was still some apprehension at not really knowing how their students were going to answer the questions. Confidence during the prediction task was never very high.

Student outcomes on CINS. In order to determine if the teachers' predictions of their students' alternative conceptions were accurate, the CINS was administered to each teacher's students first as a pre-test approximately 3-4 class meetings before each teacher's instructional unit on evolution began. Each student received a hard copy of the CINS. Students were strongly discouraged from writing answers on this hard copy, as each student was provided with a separate answer sheet. Both CINS questions and answer sheets were collected by each teacher. The results were then compiled by the principal researcher with the assistance of 2-3 local university student tutors.

Modifications made on the CINS (refer to modification procedure described in Chapter 4 in "Methodology: Data Analysis" section) needed to maintain the original version's validity. As a result, the modified CINS underwent a PCA with the current study's student participants (n=339), who were mostly (> 95%) enrolled as ninth graders. A small portion (< 5%) of the study's student participants were classified as tenth, eleventh, or twelfth graders. The CINS was originally validated on a population of undergraduate community college students (n=206) not majoring in biology. It also underwent a PCA and the results demonstrated "strong support for the internal validity of the CINS's underlying measurement structure" (Anderson et al., 2002, p. 968). The PCA, along with all other quantitative measurements and analyses included in this study, was conducted using SPSS statistical software.

***Principle components analysis summary on CINS*.** Like Anderson et al.'s (2002) original study, this study's PCA indicated eight components should be extracted due to the number of eigenvalues > 1 rule. Therefore, eight components were examined using a varimax rotation. The current study maintained the same criteria for determining the final PCA solution as Anderson et al. The criteria included: "a) having a large proportion of the total matrix variation explained, b) having a high number of items with a strong (> .40) loading on at least one component, c) having a minimum number of complex items (items with strong loadings on more than one component), and d) having a component pattern that was theoretically interpretable" (p. 966).

In contrast to Anderson et al.'s optimal seven-component extraction, the current study retained the eight-component extraction, which accounted for 55% of the total variance (Anderson et al.'s seven components accounted for 53% of the total variance). The comparative results from both rotated component matrices are found on Table 10. In

Anderson et al.'s PCA all 20 items had a loading of > .40 on at least one component. The current study had 16 items which loaded > .40 on at least one component. No items loaded > .40 on multiple components in the current study (versus original study's question 12 which loaded on components 3 and 5). Striking differences can be seen when examining the specific pairs of items. In the original study, "9 of the 10 pairs of items that represented the 10 different evolutionary concepts emerged together on the same component" (p. 966). That pattern is not readily seen in the current study, with the exception of questions 4 and 13, which probed for *change in a population.* In addition, the current study shows seemingly unrelated questions emerging on the same component (e.g., questions 11, 12, and 9 all loading on component 2). The fact that there is contrast between these and Anderson et al.'s results may indicate the CINS is also detecting these students' lack of expertise with natural selection concepts, in that the students could be responding to surface features of the questions, as opposed to deeper conceptual understanding. However, at the ninth grade level, this surface-level response is most likely to be expected.

	Component							
Item	1	2	3	4	5	6	7	8
Biotic Potential								
1			.624		.672			
11		.594	.714					
Population Stability								
3					.845	.591		
12		.667	.455		.596			
Natural Resources								
2	.706		.684					
14	.502							
Limited Survival								
5	.569		.756					
15	.589				.443			
Variation w/in a Population								
9		.569					.737	
16	.669						.547	
Inherited Variation								
7	.502			.513				
17	.743	.687						
Differential Survival								
10						.769		
18						.472		.562
Change in a Population								
4				.406 .636				
13				.671 .722				
Origin of Variation								
6		.501						.725
19		.659					.667	
Origin of Species								
8				.418				
20				.593				

Table 10: Principle components analysis comparison for CINS of Anderson et al. (2002) and current study. Shaded cells are values for the current study.

Communication of student outcomes to teachers. Pre-test responses were communicated to the teachers in the form of an individualized teacher summary, which reported (according to each class and total students) the overall average number of correct responses answered on the CINS, average score, and the percentages of students answering each question's answer choices. This report served as a formal gauge to each teacher as to how their students were thinking about natural selection concepts before their individual instructional unit began. An example of this summary from Teacher B's pre-test results for CINS question #1 is shown in Figure 8 below.

Answer problems are grouped according to the natural selection concept they are designed to address. Answer choices with (*) are correct. All other answer choices are alternative conceptions students may possess.

	PER. 1 N=8	PER. 2 N=21	PER. 4 N=14	PER. 5 N=20	PER. 7 N=18	TOTAL N=81
AVG. # CORRECT ANSWERS	5.63	6.38	7.36	6.85	7.39	6.81
AVG. SCORE	28.13%	31.9%	36.79%	34.25%	36.94%	34.07%

#1 Biotic Potential	PER. 1 N=8	PER. 2 N=21	PER. 4 N=14	PER.5 N=20	PER. 7 N=18	TOTAL N=81
A Organisms only replace themselves.	13%	10%	7%	20%	6%	11%
B Populations level off.	0%	14%	14%	30%	6%	15%
C* All species have such great potential fertility that their population size would increase exponentially if all individuals that are born would again reproduce successfully.	63%	5%	57%	35%	89%	42%
D Populations level off.	25%	71%	21%	15%	0%	28%

Figure 8: Example of student pre-test summary results presented to Teacher B.

The CINS was also administered as a post-test to each teacher's students. All post-tests were administered on or around the final day of each teacher's instructional unit and served as a measurement of learning gains from each teacher's instructional unit. Each student received a hard copy of the CINS and new answer sheet that was specific for the post-test administration. As was done with the pre-tests, the post-test results were similarly summarized and communicated back to each teacher in time for his/her post-instruction interview (discussed below).

Pre-instruction/observation interviews. Each teacher participated in an individual pre-instruction/observation semistructured interview, which provided information about each teacher's background and classroom experience, evolutionary beliefs, perspectives on gauging student knowledge, and overall approaches to teaching science and evolution. In addition, the teachers were asked about how they went about adjusting their lessons based on student understanding, the lessons they had chosen for their individual instructional units, how much time was usually allotted to the unit, the evolutionary concepts they found their students having a difficult time understanding (applicable to the more experienced biology teachers), and the overall goals of the instructional unit, that is, the concepts and ideas they believed were important to get across to their students. Specific interview questions are found in Appendix D. Each interview took place approximately 2-4 class meetings before each teacher's instructional unit on evolution formally began and lasted 40-50 minutes. These interviews were audio recorded.

Common planning meeting observations. Tobin's biology teachers officially met once a week to common plan. This 45-minute period was built within their schedules and designated as a time for the teachers to share lesson plans and resources. How this time was used may have had an influence on the instructional strategies and activities that were used for the evolution instructional unit. Therefore, it was important to take note of any conversations among these teachers that centered on students' prior knowledge, particularly alternative conceptions, and how it may have informed the teachers' lesson planning. The principal researcher attended and observed all of these meetings recording events and topics of conversation in the form of field notes. These meetings were also audio recorded.

Classroom observations. Classroom observations were a major data source. Using the same observation instrument developed by Morrison and Lederman (2003) that was used for pilot study #2 (see Appendix B), any teacher/student questions, presentation of information, and written work involved in the potential identification of student alternative conceptions was noted and recorded. A schedule was used to consistently observe an afternoon class from each teacher during the instructional unit. As a result, the following teachers' classes were formally observed and video recorded by me: Teacher D's 5^{th} period, Teacher C's 6^{th} period, Teacher B's 7^{th} period, and Teacher A's 8^{th} period. With the exception of Teacher C's Pre-AP biology 6^{th} period class, all other observed classes were regular biology classes. All observations lasted the entire length of each class. Classes were observed and video recorded only when the teachers were present. If there was a substitute or another teacher covering one of these classes, there would be no formal observation and video recording would not take place. All classes were approximately 45-50 minutes in length and scheduled to meet every day. In addition to recording formal observations, all the other classes from each teacher were recorded for future analysis, but not analyzed as part of the current (third) study.

The observations were important in supplying information about each teacher's approach to teaching evolution, that is, instructional strategies being used and modified and the types of interactions taking place between each teacher and his/her student(s) and among the students themselves. The observations also allowed for triangulation of each teacher's responses from his/her interviews with actual documented classroom events.

Daily interviews. In order to gauge how the teacher participants were using the pre-test student information from the CINS, each teacher was asked each day about the student knowledge he/she was using to make instructional decisions. All daily interviews took place immediately after almost every classroom observation and lasted approximately 4-10 minutes. The student CINS results were never mentioned specifically by the principal researcher during these interviews; rather, any discussion of the CINS's utility was left up to each teacher. These interviews were audio recorded. Specific interview questions are found in Appendix D.

Post-instruction/observation stimulated recall interviews. Each teacher also participated in an individual post-instruction/observation stimulated recall semistructured interview (See Appendix D) in which they were asked to view a short video segment of his/her teaching and reflect upon his/her thinking and teaching during that particular segment. The video clips chosen for these specific interviews covered situations where some sort of teacher and student (whole group, small group, or individual) interaction was taking place. Most examples of segments involved one of the teachers asking his/her students about their (the students') prior knowledge or experiences with the subject matter, but the clips were not necessarily relegated to just these instances. The clips also involved students explaining a concept in their own words to their peers and/or teacher.

This post-instruction interview was also an opportunity for each teacher to: 1) relay insights and reflections about the issues and ideas that were raised by the students during the instructional unit; 2) explain the rationale behind certain activities that were chosen for the instructional unit; 3) discuss adjustments he/she made to the lessons and the motives behind those adjustments; and 4) discuss the utility of the CINS as part of his/her teaching practice. These interviews took place 3-4 days after the conclusion of each teacher's instructional unit, lasted approximately 45-60 minutes, and were audio-recorded.

A data collection matrix identifying the data sources for each research question is shown in Table 11.

Research Question	Data Sources	Interview Questions
1. Does a group of biology teachers' self-professed orientations to science teaching and evolution align with lesson implementation?	Pre-instruction/observation interview	#4, 5, 6, 7, 9, 10, 21, 22, 23, 24, 25
	Common planning meeting observations	
	Classroom observations, video	
	Post-instruction/observation stimulated recall interview	#4, 6, 7, 8, 9
2. Aided by the use of a concept inventory, what is the nature of these teachers' *knowledge of their students' alternative conceptions* with regards to natural selection (Anderson et al., 2002), specifically? How does the teachers' elicitation of students' evolutionary alternative conceptions inform their teaching practices?	Teachers' predictions of alternative conceptions on CINS	
	Student outcomes on CINS (pre-test)	
	Common planning meeting observations	
	Pre-instruction/observation interview	#8, 15, 16, 17, 18, 19, 20
	Classroom observations, video	
	Daily informal interviews	#1-3
	Post-instruction/observation stimulated recall interview	#2, 3
3. Does the teachers' *subject matter knowledge (SMK),*	Teacher content knowledge score on CINS	

with respect to natural selection, relate to the knowledge of their students' alternative conceptions? How does the teachers' SMK manifest itself when students reveal their alternative conceptions?	Teachers' predictions of alternative conceptions on CINS	
	Pre-instruction/observation interview	#11, 12, 13, 14
	Classroom observations, video	
	Post instruction/observation stimulated-recall interview	#5
4. How do the teachers view the concept inventory's utility as a classroom tool for gauging student understanding of natural selection?	Pre-/Post-instruction/observation interviews, daily interviews	#10-#13 (post-interview)
	Common planning meetings	
	Classroom observations, video	
5. As measured by the concept inventory, do the teachers' respective students maintain or modify their alternative conceptions regarding natural selection?	Student outcomes on CINS (pre- and post-test)	

Table 11: Data collection matrix for current study.

Methods of Data Analysis

All teacher interviews were transcribed immediately following the observation cycle and subsequently reviewed for accuracy by the teacher participants. As each interview was transcribed, it would be sent (through email correspondence) to the respective teacher for review. Videos were viewed in order to ensure important aspects of each teacher's practice were not missed. All interviews and videos were transcribed and coded using NVivo Qualitative Analysis software. After transcription and initial coding, a detailed profile of each teacher and his/her classroom practice was then created. Hierarchical coding categories from the data sources related to science teaching and evolutionary orientations, methods of eliciting and awareness of student alternative conceptions, and frequency of probing for alternative conceptions were identified using the constant comparative method (Glaser & Strauss, 1967) and provided a framework with which to describe the teachers' practices. The principal researcher went through several iterations of coding from each teacher's data source. As each teacher profile was developed, the multiple data sources were triangulated in order to further identify patterns and construct explanations (Yin, 2003). The profiles were then used to compare and contrast each teacher in terms of topic-specific content knowledge, knowledge of students' alternative conceptions, and individual interview responses. These cross-case comparisons allowed a more meaningful understanding of the data, as "understanding unique cases can be deepened by comparative analysis" (Patton, 2002, p. 56).

In order to answer research question #1, each teacher's orientation to science teaching was individually analyzed first in terms of how each teacher described: (a) the teacher roles during a typical science lesson, (b) perceptions of himself/herself as a science learner, and (c) ideal images of teaching, including student roles. Then, each teacher's orientation to evolutionary theory was analyzed according to: (a) his/her acceptance of evolutionary theory and (b) the goals and purposes of his/her individual evolutionary instruction. Emergent themes were identified from the teachers' responses to the specific interview questions for orientations (see Table 11) and member-checked by the teachers for accuracy. Next, each teacher's evolutionary lesson implementation was examined for alignment to the identified individual science teaching and evolutionary orientations. In order to examine how closely each teacher's evolutionary lessons aligned with their respective orientations toward science teaching and evolutionary theory, each teacher's video-recorded lessons were reviewed and further coded according to each teacher's emergent themes from these constructs (see Tables 12 and 13).

	Coding Constructs for Orientation to Science Teaching		
	Teacher role	**Student role**	**Ideal science lesson**
Teacher A	provide information	actively receive knowledge	following specific sequence: engagement activity, teacher-led lecture, student-led investigation
Teacher B	make scientific concepts less abstract	actively receive and construct knowledge	following specific sequence: teacher-led lecture, student-led investigation, closure with assessment
Teacher C	mentally prepare students for learning	construct knowledge	students discussing scientific ideas while working with hands-on activity
Teacher D	provide information and facilitate learning process through differentiated instruction	actively receive and construct knowledge	following specific sequence: review previous lesson concepts, engagement activity, teacher-led lecture, student-led investigation

Table 12: Summary of each teacher's science teaching orientation themes according to construct.

	Coding Constructs for Orientation to Evolutionary Theory	
	Acceptance	**Purposes and goals of instructional unit**
Teacher A	yes	• scientific evidence supports evolution • populations evolve, not individuals • evolution takes time to occur • compartmentalization of concepts
Teacher B	yes	• organisms evolve from a common ancestor
Teacher C	ambivalent	• evolution takes time to occur • de-emphasize human-centric way of thinking • retain openness to alternate ideas of evolution

Teacher D	yes	• nature of evolution as a scientific theory • organisms evolve from a common ancestor • importance of key vocabulary

Table 13: Summary of each teacher's orientation to evolution and themes used for coding to lesson alignment.

In answering research question #2, the teachers' PCK for student ideas/areas of difficulty/alternative conceptions was assessed by determining how accurate each teacher was at predicting his/her students' alternative conceptions on the CINS. This was done by comparing the teachers' predictions to their students' actual answers. First, the frequencies at which each teacher's students answered each answer choice for all 20 questions on the CINS had to be determined. These frequencies were then used to establish the accuracy of the prediction(s) each teacher made for each question. The "prediction accuracy" for each question was calculated by dividing the total percentage of a teacher's predictions for a certain number of answer choices by the maximum percentage of that teacher's students' actual incorrect answer choices for the number of predictions the teacher made for that question. For example, imagine an item in which students' answers were distributed as follows: 40% A, 30% B, 20% C, and 10% D (with A being the correct answer choice). If a teacher predicted her students would answer B as the most common alternative conception, then she would have a prediction accuracy of 1.0 (30% / 30%). If, instead, she predicted C, then she would have a prediction accuracy of 0.67 (20% / 30%). If she predicted C and D as the most common alternative conceptions, she would then have a prediction accuracy of 0.60 ((20% + 10%) / (30% + 20%)).

It must be noted that this method for prediction accuracy was used on occasion to accommodate instances when any of the teachers made predictions for "the most common answer(s)" as opposed to the "most common alternative conception(s)." During these instances, the prediction accuracy for each question was calculated by dividing the total percentage of a teacher's predictions for a certain number of answer choices by the maximum percentage of the teacher's students' actual answer choices for the number of predictions made for that question. For example, if we imagine the same distribution as above and a teacher predicted her students would answer C and D most frequently, she would then have a prediction accuracy of 0.43 [(20% + 10%) / (40% + 30%)]. In some cases the teachers predicted their students would have no difficulty with a particular question and predicted the correct answer choice for them. Whenever this occurred, these predictions were not counted towards the total prediction accuracy score, which focused on the teachers' knowledge of students' alternative conceptions. The teachers' individual prediction accuracy scores were then analyzed for statistical significance using a one-way analysis of variance (ANOVA).

In addition to the describing the different methods the teachers used to elicit their students' alternative conceptions and how the teachers used this information about their students, research question #2 also determined the amount of teacher-student interactions dedicated to eliciting alternative conceptions. The amount of these interactions was determined from the Morrison and Lederman observation instrument (see Appendix B) and by reviewing the video for each teacher's formally observed classes. Each time a teacher asked a new formal question that probed student thinking about a concept before an evolutionary concept was introduced, the interaction was coded as "probing for alternative conceptions and prior knowledge". See Appendix E for this aspect of research question #2's coding scheme.

In analyzing research question #3, the teachers' prediction accuracy scores were categorized according to those CINS questions the teachers personally answered either correctly or incorrectly, and these scores were then further analyzed for statistical significance with a one-way ANOVA. In addition, RQ#3 mainly dealt with how the teachers' SMK was used in real time when their students' alternative conceptions became apparent. The students' alternative conceptions often became revealed when they initiated comments or questions to their respective teacher. Therefore, these student-teacher interactions were analyzed for emergent themes by reviewing the video for each teacher's formally observed class. The emergent themes that were identified here were also member checked for accuracy.

Research question #4 was analyzed largely by a review of the extent with which each teacher incorporated CINS concepts into his/her practice and how any information from the CINS (the instrument itself or student results) was used to plan and/or revise lessons and reflect upon the instructional unit. The overall presence of the CINS's concepts in the teachers' classes was measured by reviewing their instructional activities and video for these classes. Statistical significance of the concepts' presence was determined through a one-way ANOVA. Further examination of the concepts' presence was made by counting the number of teacher-student interactions. See Appendix E for the coding scheme of this aspect of research question #4. Each time a teacher asked a new formal question or made a statement that incorporated the use of a CINS concept, the interaction was counted as a separate instance. In a similar fashion, each time a student initiated and mentioned a CINS concept in the form of a formal question to the teacher, that interaction was counted as well. In some cases, teacher or student follow-up questions were normally not included in the count because they usually were still considered to be in the main line of thought during the entire interaction. For an example of how one such interaction was coded with this particular scheme, see Appendix E. Some interactions may have had as many as ten teacher-student exchanges or as few as one based on how often the line of thought between concepts changed. Student-student interactions were not included so as to maintain focus on the teachers' use of the CINS as a classroom tool.

Research question #5 was analyzed by using the student outcomes from the CINS pre- and post-tests. Overall student scores on the pre- and post-tests were grouped according to each teacher, analyzed with a paired t-test, and measured for effect size with Cohen's d. The overall student outcomes were also analyzed for performance on individual CINS concepts. These specific results are reported as descriptive statistics.

Chapter Six: Results

The results in this chapter are presented according to each of the current study's research questions. Research question #1's results became separated into two components so as to distinguish the teachers' science teaching orientation (now research question #1A) from their orientation to evolutionary theory (now research question #1B). However, the two components are still retained as part of research question #1 due to their structural relatedness. The remaining research questions' results are presented and discussed according to their original format. A summary that describes the most pertinent findings is presented at the end of each research questions' results.

Research Question #1A: Does a group of biology teachers' self-professed orientations to science teaching align with lesson implementation?

A teacher's orientation to science teaching influences instructional decisions made during planning and teaching and references his/her perceptions of the roles of teachers and learners as well as the purposes and goals for science teaching (Abell, 2007; Grossman, 1990; Handal, 2003; Magnusson et al 1999). This aspect of a teacher's PCK can have a direct influence on the types of instructional activities and strategies that are used during a lesson. The results for this research question are presented in terms of a cross-case analysis of how each teacher described: 1) perceptions of himself/herself as a science learner; 2) the teacher roles during a typical science lesson; and 3) ideal images of science teaching, including student roles.

The themes resulting from the teachers' descriptions of teacher and student roles and ideal science lessons were then checked for alignment to their lessons on evolution. Every teacher's alignment of his/her lessons was examined with his/her respective science teaching orientation through the use of his/her implemented instructional activities, which are listed in Table 14. The use of each teacher's instructional activities was coded according to each teacher's emergent constructs regarding science teaching orientation. If the majority of a teacher's lessons (> 5 or 6) were consistent with his/her themes from science teaching orientation constructs mentioned above, then alignment was confirmed. However, before these results are presented, it is helpful to provide context by seeing how the teachers described their own perceptions of how they best learned scientific concepts.

Perceptions as science learners. The teachers' descriptions of how they best learned scientific concepts provided insight into how they would possibly plan their instructional units on evolution and what instructional strategies they would potentially use.

Absorber of information. When asked how they best learned scientific concepts, both Teachers A and C mentioned they enjoyed participating in occasional hands-on and laboratory-oriented activities, but mostly saw themselves as absorbers of information, particularly through lectures and presentations. An absorber of different means, Teacher D liked to work independently, especially when reading about concepts through textbooks and other written material. In addition, Teacher D preferred a differentiated approach for herself when reinforcing the understanding of a scientific concept, especially through a combination of being exposed to a variety of examples, illustrations, models, and other representations, and participating in the scientific process. Teacher D never thought it was helpful for her to "just sit there and watch them [instructors] talk."

Active participant in all aspects of scientific process. Teacher B definitely perceived herself as an active science learner. While she admitted she needed to spend time to learn and become familiar with vocabulary and concepts (i.e., listening to lectures, reading different text resources), she was cognitively aware that concepts made more sense to her once she had a chance to "get her hands dirty" with the subject matter whether it was in terms of participating in the investigative scientific process or other hand-on experiences, such as modeling.

Teacher roles during a typical science lesson. The teacher role in a typical science lesson was the first sub-category of science teaching orientation that was examined. Each teacher described what his/her role was in the classroom before each of their instructional units on evolution began. Their descriptions of the teacher role helped inform the dynamics of teacher-student discourse and the rationale for the use of different instructional strategies and activities. The common themes and results for lesson alignment are described below.

"Guide" through biology—provide information. Teacher A saw herself as giving her students a quick one-year tour through biology. On that tour, she believed it was her duty to "point out the highlights" and "interesting things…that they will remember when they go home from their vacation" (Pre-instruction interview, 3/9/12). In her view, it was her responsibility to decide what concepts were important for her students to know and how to best have her students learn that information.

Lesson alignment. Throughout her instructional unit, Teacher A made all decisions about which concepts she wanted her students to learn. With the state standards as her guide, she determined the sequence of her lessons and which instructional activities to include as part of her unit. As can be seen from Table 14, Teacher A's 9-10 day unit included the reading of a scientific article and three major teacher-led presentations in which she was relaying information to her students. All other activities were teacher-led. For example, Teacher A took the lead with the natural selection candy grab and drift worm population evolution simulations by either guiding the questioning that took place, having students collect a specific form of data, or asking her students for specific results from data that was collected.

Day of Instructional Unit	Teacher A	Teacher B	Teacher C	Teacher D
1	3/20/12 LESSON TOPIC: Background of Evolution	3/26/12 (STATE TESTING) LESSON TOPIC: Background of Evolution	3/28/12 LESSON TOPIC: Setting the Stage for Evolution--Deep Time, Geology	3/19/12 LESSON TOPIC: Background of Evolution
	Written Warm-Up Questions: Introduction to Evolution	Student written ideas and thoughts on evolution	Video: "Simpsons" Introduction to Evolution and emphasis on deep time	Written ideas and thoughts on evolution
	Teacher-led lecture & presentation: Introduction to evolution, Darwin's voyage	Video: "What Darwin Never Knew"	Video: "Amazing Planet", emphasis on deep time, 20 ways video is related to evolution	Video: "Simpsons" Introduction to Evolution
				Teacher-led lecture & presentation: Introduction to evolution, Darwin's voyage, natural selection vs. artificial selection, adaptations
2	3/21/12 LESSON TOPIC: Natural Selection	3/27/12 (STATE TESTING) LESSON TOPIC: Background of Evolution	3/29/12 LESSON TOPIC: Setting the Stage for Evolution--Deep Time, Geology	3/20/12 LESSON TOPIC: Natural Selection
	Teacher-led lecture & presentation: Natural selection, artificial selection, fitness, adaptations	Video: "What Darwin Never Knew"	Video: "Amazing Planet", emphasis on deep time, 20 ways video is related to evolution	Written Warm-Up Questions: Introduction to evolution, Darwin's voyage
				Teacher-led lecture & presentation: Darwin's voyage, Darwin's finches, natural selection, adaptations
				Video: Short overview of natural selection
				Teacher-led demonstration: Computer-generated

				natural selection
				Foldable on natural selection: Defining *natural selection, descent with modification, survival of the fittest, struggle for existence*
3	3/23/12 LESSON TOPIC: Natural Selection	3/28/12 LESSON TOPIC: Background of Evolution	3/30/12 LESSON TOPIC: Thoughts and Ideas on Evolution	3/21/12 LESSON TOPIC: Natural Selection, Adaptation, Fitness
	Written Warm-Up Questions: Adaptations, biological fitness	Video: “Simpsons” Introduction to evolution	Evolution word cloud creation (generating individual word list, narrowing list with a partner)	Written Warm-Up Questions: Natural selection, struggle for existence, descent with modification, adaptations
	Natural Selection Candy Grab Simulation	Teacher-led lecture & presentation: Introduction to evolution, Darwin’s voyage, natural selection vs. artificial selection, adaptations		Natural Selection Candy Grab Simulation
	Animal Adaptations Drawing			Imaginary creature adaptation drawing
4	3/26/12 (STATE TESTING) LESSON TOPIC: Background & Current Research on Evolution	3/29/12 LESSON TOPIC: Evidence for Evolution	4/2/12 LESSON TOPIC: Thoughts and Ideas on Evolution	3/23/12 LESSON TOPIC: Natural Selection, Adaptation, Fitness
	Video: “What Darwin Never Knew”	Teacher-led lecture & presentation: Evidence for evolution	Evolution word cloud creation (generating individual word list, narrowing list with a partner)	Written Warm-Up Questions: Natural selection, biological fitness
				Imaginary creature adaptation drawing
5	3/27/12 (STATE TESTING) LESSON TOPIC: Background & Current Research on Evolution	3/30/12 LESSON TOPIC: Evidence for Evolution	4/3/12 LESSON TOPIC: Mechanisms and “Drives” of Evolution	3/28/12 LESSON TOPIC: Evidence for Evolution
	Video: “What Darwin Never Knew”	Teacher-led lecture & presentation: Evidence for evolution	Watching different representations of evolution: Commercials and videos	Whole-class oral review of evolutionary concepts (learned thus far)
				Teacher-led lecture & presentation; guided notes & worksheet: Evidence for evolution
6	3/28/12 LESSON TOPIC: Natural Selection & Evidence for Evolution	4/2/12 LESSON TOPIC: Natural Selection	4/4/12 LESSON TOPIC: Thoughts and Ideas on Evolution of “Anything”	3/29/12 LESSON TOPIC: Evidence for Evolution & Changes in Populations

<table>
<tr><td rowspan="3"></td><td>Foldable on Natural Selection: Defining fitness, adaptation, survival of the fittest, struggle for existence</td><td>Written Warm-Up Questions: Evidence for Evolution, Natural Selection vs. Artificial Selection, Adaptations</td><td rowspan="3">Creation of 30-sec. evolutionary music videos (the evolution of any one thing)</td><td>Written Warm-Up Questions: Biological fitness, adaptations, overview of natural selection, evidence for evolution</td></tr>
<tr><td rowspan="2">Teacher relay of information: Evolution of Hawaiian Crickets</td><td rowspan="2">Natural Selection Candy Grab Simulation</td><td>Teacher-led lecture & presentation; guided notes: Evolution of populations, sources of variation</td></tr>
<tr><td>Teacher-led demonstration: Using playing cards to represent gene shuffling</td></tr>
<tr><td rowspan="5">7</td><td>3/29/12 LESSON TOPIC: Evidence for Evolution</td><td>4/3/12 LESSON TOPIC: Speciation</td><td>4/5/12 LESSON TOPIC: Thoughts and Ideas on Evolution of “Anything”—Work day</td><td>3/30/12 LESSON TOPIC: Evolution of Populations</td></tr>
<tr><td rowspan="4">Whole-Class Questioning of Evidence for Evolution tied to “What Darwin Never Knew” video</td><td rowspan="2">Written Warm-Up Questions: Evidence for Evolution, Natural Selection</td><td rowspan="4">Creation of 30-sec. evolutionary music videos</td><td>Written Warm-Up Questions: Evidence for evolution</td></tr>
<tr><td rowspan="3">Teacher-led lecture & presentation: Evolution of populations, directional selection, stabilizing selection, disruptive selection, speciation</td></tr>
<tr><td>Speciation Simulation</td></tr>
<tr><td>Speciation Worksheet</td></tr>
<tr><td rowspan="5">8</td><td>3/30/12 LESSON TOPIC: Evolution of Populations</td><td>4/4/12 LESSON TOPIC: Fitness & Genetic Drift</td><td>4/9/12 LESSON TOPIC: Natural Selection</td><td>4/2/12 LESSON TOPIC: Evolution of Populations—Genetic Drift</td></tr>
<tr><td>Written Warm-Up Questions: Evidence for Evolution</td><td>Written Warm-Up Questions: Nature of Darwin’s Theory, Speciation</td><td>Presentation of 30-sec. evolutionary music videos</td><td>Written Warm-Up Questions: Speciation, Evidence for Evolution</td></tr>
<tr><td rowspan="2">Teacher-led lecture & presentation: Evolution of Populations</td><td rowspan="2">Teacher-led lecture & presentation: Biological Fitness, Evolution of Populations</td><td rowspan="2">Video: Introduction to Natural Selection</td><td>Teacher-led lecture & presentation: Evolution of populations, genetic drift</td></tr>
<tr><td>Teacher-led simulation: Evolution of Drift Worm Population</td></tr>
<tr><td rowspan="2">9</td><td>4/2/12 LESSON TOPIC: Evolution of Populations—Genetic Drift</td><td>4/5/12 LESSON TOPIC: Evolution of Populations-- Genetic Drift</td><td>4/10/12 LESSON TOPIC: Natural Selection & Speciation</td><td>4/3/12 LESSON TOPIC: Evolution of Populations—Genetic Drift</td></tr>
<tr><td>Written Warm-Up Questions: Review of</td><td>Written Warm-Up Questions: Evolution</td><td>Teacher-led lecture & presentation: Natural</td><td>Written Warm-Up Questions: Evolution</td></tr>
</table>

	Fitness, Adaptations, Natural Selection, Evidence for Evolution	of Populations	Selection, Speciation	of Drift Worm Population
	Teacher-led simulation: Evolution of Drift Worm Population	Video: Evolving Populations With Genetic Drift Using Poker Chips	Presentation of 30-sec. evolutionary music videos	Teacher-led lecture & presentation: Genetic drift, founder effect, bottleneck effect
10		4/10/12 LESSON TOPIC: Unit Review	4/11/12 LESSON TOPIC: Background of Evolution	4/4/12 LESSON TOPIC: Unit Review
		Whole-class oral and written review on evolution	Teacher-led lecture & presentation: Lamarckian ideas, Charles Darwin, Darwinian influences, Natural Selection, Artificial Selection, Evidence for Evolution, Speciation	Whole-class oral and written review on evolution

Table 14: All teachers' implemented instructional activities during his/her instructional unit on evolution.

Make scientific concepts less abstract. Plainly and simply, Teacher B articulated the overall role of a science teacher as one who had the responsibility for students to learn science. From her experience, Teacher B believed too many students thought science was difficult to understand and a subject to which they could not relate. According to Teacher B, the best way for a teacher to make science more approachable and less abstract was for students to realize how much science was part of their daily lives. The methods she thought worked effectively to achieve this realization were with different forms of instructional strategies and activities, especially those with which students could find familiarity. In Teacher B's view, implementing these methods would have a positive impact on students by increasing their confidence and assurance in carrying out scientific endeavors.

Lesson alignment. Teacher B described various ways in which she tried to make scientific concepts more relatable to her students. Among them was her use of videos to help explain scientific concepts and describe the practical applications of science. Teacher B's 10 day unit included various uses of video (see Table 14). Some of these videos were the focal point of the lesson (e.g., "What Darwin Never Knew") and others served to engage the students (e.g., "Simpsons" introductory video) or supplement the explanation of a concept (e.g., poker chip video). In essence, these three videos all served different functions in attempting to make the overall framework of evolutionary theory easier to understand.

Consistent with her self-described perception as a science learner, another way Teacher B described to make scientific concepts less abstract was through the use of "hands-on" activities. In Teacher B's view, hands-on activities involved anything students could manipulate, whether it was participating in a class simulation or short laboratory exercises, building models, or drawing diagrams. Following this idea, the activities did not have to necessarily involve students using a specific scientific skill set, such as developing a researchable question or collecting and analyzing data. During her instructional unit, Teacher B had her students participate in two types of these activities (natural selection candy grab simulation and speciation simulation) on two different class meetings, and by her own admission, Teacher B knew just two activities was not enough to make a difference in how her students developed deeper conceptual understanding:

> I didn't have as much hands-on as I would have liked...I would have liked a lot more hands-on and then give them the quiz. So kind of follow it with somewhat of the sequence that I normally follow. I just would have preferred more labs, more hands-on labs. (Post-instruction interview, 4/25/12)

It must be noted, however, that Teacher B made attempts to have her students better understand evolutionary concepts with the use of different visual representations. Even though Teacher B did not specifically mention the representations as one of the methods she would make scientific concepts less abstract, she would use these representations as part of her teacher-led presentations to further explain a particular concept. Representations were part of all Teacher B’s presentations (see Table 14 for the occurrences of Teacher B’s teacher-led lectures) and accompanied almost every slide she showed. The following interaction between Teacher B and me exemplifies her rationale for the use of visual representations to further aid in learning a concept:

> ML: Because...I mean it wasn't like it was just text up there [in your presentation] because you also had some graphic representations...And so you must have thought those were important for a reason...
> Teacher B: Give them that those little thought processes like when we were going through the evolution of a horse, and then the different evolutions of the camels, and then we went to *Homo sapien*. And they were able...those images kind of allowed them to see, "Oh...Fossil records do help with evidence." So that's kind of why I left those images in there. (Daily interview, Day 4, 3/29/12)

There was one particular instance where Teacher B’s use of a visual representation encouraged deeper conceptual questions than she was self-admittedly used to seeing from her students. In the following example, Teacher B was presenting the evidence for evolution and showed her students two pictures of a grizzly and polar bear to provide an example of geographic distribution. It must be noted that Teacher B, herself, exhibited an alternative conception of her own (immediately after S3’s initial comment):

> *To help explain the concept of geographic distribution, Teacher B shows pictures of a grizzly bear and a polar bear. Teacher B describes the features of the grizzly bear that make it well-suited for its environment. Teacher B does the same for the polar bear.*
>
> S1: Miss, what if you put the grizzly bear in the North Pole?
> Teacher B: It probably wouldn't survive.
> S1: Let's say it would survive.
> Teacher B: It probably wouldn't survive for a while.

S2: What if you put the...
S3: So how did...
Teacher B: Eventually...maybe there would be some adaptations to him that the offspring would get and then those adaptations would carry on and carry on and carry on. So it's possible...maybe, but it'd take a long time.
S2: For the whole...(*inaudible)*
Teacher B: But immediately, it probably would die off.
S3: What if you mix them?
Teacher B: You'd have to do it artificially. They probably still could, but they wouldn't want to because now they're separate species...
S2: Miss, what if you just put the polar bear in the water?
Teacher B: He can swim...Actually, these guys *(referring to the grizzly bear)* are known to swim a little too.
S2: So what if you put the polar bear in the grizzly's environment, but just keep the polar bear in the water?
Teacher B: He *(referring to polar bear)* probably wouldn't survive in this environment *(referring to grizzly's environment)*.
S2: Not even in the water?
Teacher B: It'd probably be too hot for him. He'd probably start dying.
S2: The water's hot?
Teacher B: Remember they're in different environments. Those environments kind of help them with their survival.
S2: What if you put it like in a zoo?
Teacher B: Which is why these guys are dying off *(referring to polar bears)*...'cause their environments are starting to die off.
Assorted inaudible student chatter...
S3: So how...you said after a while they would adapt, right? *(Referring to previous line of thought with the grizzly and polar bears being swapped)* But how, if he's dying, you can't make more bears?
Teacher B: Because maybe a few will survive...not many, but maybe a few would survive and they would reproduce, and then more would survive...But it would be a very slow process...(Class lesson, Day 4, 3/29/12)

It is evident from this exchange between Teacher B and her students that the discussion began to proceed in different lines of thought than what she intended (she later stated that she was pleasantly “surprised” by the type of discourse her students were displaying), but Teacher B allowed her students’ questions to continue in spite of her internal pressure to proceed with the next aspect of her lesson. Teacher B speculated that had it not been for the pictures of the bears in her presentation, her students may not have been prompted to begin asking questions about the animals.

Balance between providing information and having students do intellectual work. Teacher D saw herself as striking a balance between providing information to her students and her students being accountable for their own learning. However, she knew that striving to have student-directed lessons was the best way for her students to learn science concepts:

> I'm there to give them the information, but I want them [the students] to also be involved in the learning. So…I want to ask them the question, but I want them to really take the time to kind of…be kind of more student-directed too sometimes…not always teacher-directed, but student-directed…'cause I think that's the way they're going to learn the best…if you have them trying to figure out…why something is the way…like give them an assignment where they have to kind of think about it a little bit or give them a question they kind of have to think about it…(Pre-instruction interview, 3/9/12)

In Teacher D's view, it was her responsibility to determine which concepts were important for her students to know and provide opportunities for her students to think hard about scientific concepts.

Lesson alignment. Teacher D formally provided information to her students mainly through teacher-led lectures and presentations. Through the course of her 10-day unit, Teacher D conducted 7 formal presentations (see Table 14) and approximately half of these presentations were at least 20 minutes in length, which was almost the majority of the class period. Nevertheless, Teacher D ensured her students were accountable for the information that was presented to them by having them take notes (whether in a guided form or copying information verbatim) and/or completing worksheets. Teacher D never mentioned any evolutionary concepts that she failed to provide during the course of her unit.

Knowing that no single, prescribed instructional method worked best for her students to learn, Teacher D recognized that she had to provide multiple ways and opportunities for her students to do intellectual work. Teacher D's instructional unit included various forms of differentiated instruction (see Table 14). Differentiated instruction encompasses the methods and strategies that are used which provide avenues for students to learn concepts (Tomlinson, 2001). Throughout her instructional unit, Teacher D presented her students with different representations of content (e.g., videos and simulations, demonstration on gene shuffling) and various forms of assignments (e.g., foldable on natural selection concepts, imaginary creature adaptation drawing, participation in two different simulations). However, these assignments and activities were not exactly designed for her students to do the intellectual work of generating overall themes or patterns that can be seen with evolutionary processes.

By Teacher D's admission, she believed she fell short of realizing her teacher role as a facilitator of the learning process by differentiated means because she wanted to include more hands-on activities for her students, but was not able to during her unit:

> Well, unfortunately, I don't think we did as much hands-on as I would have liked to. Yeah...I would have liked more actual labs with it. But...just because of timing and things like that we weren't able to...So that wasn't necessarily ideal to what I would want…(Post-instruction interview, 4/23/12)

Perhaps Teacher D's gauge for measuring differentiated instruction in her classroom was by the number of hands-on activities she provided for her students. However, this may be a case of Teacher D not realizing the different dimensions of differentiated instruction to include different forms of student product and presenting content, along with processes provided to have students learn content (i.e., hands-on activities).

"Mentally prepare" students for learning. Teacher C saw himself as a "mental preparer" of sorts to his students. He articulated his responsibility as one of arranging for his students to be in the correct mind-set so that learning could occur. Teacher C stated he did this through a variety of ways, whether it was through "scaffolding or presentations of ideas". Whatever the method, he needed to guide his students to the proper mental place so that the optimal amount of learning could take place.

Lesson alignment. At the onset of his instructional unit, Teacher C introduced various videos that either dealt with the topic of evolution directly or indirectly with the presentation of a changing earth. In the latter case, Teacher C intended for his students to get their ideas down on paper by listing 20 ways the "Amazing Earth" video was related to evolution. In this way, Teacher C was placing his students within the context of beginning to learn evolution. From Table 14, there were other assignments that allowed opportunities for mental preparation. These other assignments included word cloud and 30-second music video creations on evolution.

During all of these assignments, Teacher C allowed his students extended class time to work on their group/individual projects, but when the time came for the students to examine each other's finished work and discuss how the assignments were related to various evolutionary concepts, this did not occur in a meaningful way. For example, it was Teacher C's intention for all his classes to see and critique the different word clouds that were generated, but this never occurred. Furthermore, because the music video assignment was so open-ended (depict the evolution of "anything", like shoes, cars, fashion), it was difficult for the students to relate the videos to any evolutionary concept once they were presented. Teacher C's students may have been mentally prepared to learn evolution through these assignments, but the scaffolding and guiding-roles Teacher C also described for himself were not present.

Teachers' views of the ideal science lesson. As a sub-category of science teaching orientation, a teacher's description of the ideal science lesson can offer perspective into what is valued in a lesson and about the discipline itself. The teachers' descriptions were also checked for alignment to their lessons on evolution.

Follow a specific sequence. Ideally, Teachers A, B, and D all commented their lessons would follow some sort of structure where there were three or four distinct stages: 1) an engagement activity/review from previous lesson, 2) teacher-led lecture and presentation, 3) student-led investigation of the current concept she would be teaching, and 4) some sort of closure in which students were assessed of the concepts and ideas they learned during the course of the lesson. Teacher D, in particular, believed her students needed to see the connection between lessons from one day to the next and thought daily reviews with her students were a necessary part of her ideal science lessons for this to occur. Integrated with the connection of previous lessons, Teacher D believed that her students' participation in engagement, hands-on, and laboratory (she did not necessarily use the terms interchangeably) activities were fundamental strategies for her students to better understand scientific concepts:

> Ideally, I love labs. I wish we had longer than 45 minutes, so I could do a really good lab, but…something that's hands-on…I think kids are interested more when it's something hands-on. They're not just sitting there listening to me talk all day, which sometimes you have to do. But, yeah…ideally, for science, I think labs or some kind of hands-on activity and relating it to something they know in real life would be ideal for a science lesson. (Pre-instruction interview, 3/9/12)

Lesson alignment: Teacher A. Teacher A described her ideal science lesson as having three main parts: 1) engagement activity to get her students excited about a specific topic, 2) teacher-led lecture for dispensation of important concepts, and 3) student-led investigation. As seen from Table 14, Teacher A did not implement any engagement activities for her students during her 10-day unit. She implemented three formal teacher-led presentations, but no student-led investigations. None of Teacher A's evolutionary lessons incorporated all three elements of her ideal science lesson.

Lesson alignment: Teacher B. Teacher B also described her ideal science lesson as having three main parts: 1) teacher-led lecture for dispensation of important concepts, 2) student-led investigation, and 3) closure with some sort of assessment that reinforced the lesson's main ideas. Teacher B implemented four formal teacher-led presentations during her 10-day unit (see Table 14), but no student-led investigations. In addition, there were not any assessments that occurred as closures toward the end of each day's lesson. Instead, all assessments (with the exception of her formal unit test) took place at the beginning of each lesson, starting on Day 6.

Lesson alignment: Teacher D. Teacher D described her ideal science lesson as having four main parts: 1) review previous lesson, 2) engagement, 3) lecture, and 4) investigation. Teacher D made it a point to review with her students on a daily basis (see Table 14). In almost every case, daily reviews (they were known to students as "Mission Countdowns") consisted of either 3-5 short-answer or multiple-choice written questions (see Figure 9 later in this chapter for an example of one such set of questions) and served as connections to the main ideas of previous lessons. Daily reviews were the first instructional activities of each lesson and always asked questions on recent previously-taught concepts, which was consistent with Teacher D's description of the ideal science lesson. After students individually completed their questions and turned them in to be graded, Teacher D always reviewed the questions with the students in the form of a whole-class question-answer discussion. She did this, not only to hear how the students answered the questions, but to create a clear classroom atmosphere of how the evolutionary concepts were to be understood (i.e., for reinforcement).

Teacher D's description of the ideal science lesson also included some sort of engagement activity that would serve as primer for her students to learn other scientific concepts. The engagement would also provide a lesson anchor of sorts—something to which the students could return toward the end of the lesson and of which to be mindful while the students were carrying out other activities. These engagement activities would occur after the daily review discussions with her students. The only time an engagement activity was implemented during Teacher D's evolutionary unit was on her first formal day of instruction when her students watched a very short (1-2 minutes) video presenting an overview of evolution using characters from the popular "Simpsons" television series. After this video was shown, Teacher D then presented her introductory lecture on evolutionary concepts and Charles Darwin's voyage to the Galapagos Islands, but the video was never discussed again by either Teacher D or her students.

Hands-on activities and scientific discourse among students. Teacher C was the only teacher who did not specifically mention any sort of structure or framework as part of his ideal science lesson. As long as his students were talking about scientific ideas while physically participating in some kind of hands-on activity, that situation was ideal to him.

Lesson alignment. Teacher C's description of his ideal science lesson involved his students doing the intellectual work while being engaged with some sort of hands-on activity. As seen from Table 14, Teacher C's students never engaged in any sort of investigation or hands-on activity during his 10-day unit. Most scientific discourse in

Teacher C's class occurred among him and his students, either as a whole class or with individual groups of students. Scientific discourse among the students themselves was relegated to when they worked with a partner to create their word clouds or music videos.

Students' role(s) during a typical science lesson. Lastly, the teachers' descriptions of a student's role during a typical lesson gave an additional angle from which to view their science teaching orientations. When describing the extent of student involvement in their typical science lessons, all four teachers could be placed along a continuum that ranged from students receiving knowledge to students constructing their own knowledge. This sub-category was also examined for alignment to each teacher's lessons on evolution.

"Active" receivers of knowledge. Teacher A envisioned her students to be active receivers of knowledge during her science lessons. In essence, she longed for students to be like herself, where students became intellectually excited and curious about the information that was presented to them. There was consistency between Teacher A's description of her ideal science lesson and the student-teacher role in the classroom. In her vision, Teacher A provided the information that was important for her students to know through an engagement and formal presentation; her students were to listen, ask questions, and become intrigued by the subject matter so as to then initiate investigation and experimentation.

Lesson alignment. In Teacher A's classroom, students had their place as receivers of knowledge. However, according to Teacher A's orientation, students needed to be engaged and curious with the information they received. When Teacher A was presenting information during a formal lecture, students were required to take notes. Intellectually-curious questions from students were always welcome by Teacher A, but did not often occur. From her observed class, approximately 5% (n=15) of the total questions asked by either Teacher A or her students during the instructional unit were actually initiated by students and a small fraction (15%, n=2) of those questions were ones that genuinely asked for interest on a topic. Teacher A drove the question-answer discourse in her classroom, as this was another method of providing information to her students and keeping them engaged. Of the total questions (n=294) asked during her instructional unit, Teacher A initiated 95% (n=279) of them, with the majority probing for comprehension (30%, n=83), recall of facts, definitions, or other information (17%, n=51), and confirmation of trends, results, or facts (16%, n=44).

Receiver and constructor of knowledge. In a somewhat similar vein to Teacher A, but slightly further along the student-centered continuum, Teacher B described the students as straddling between receiving and constructing knowledge where students could receive knowledge during her teacher-led lecture and then begin to construct their knowledge during the exploration phase.

Along with Teacher B, Teacher D could be placed at this point along the student-centered continuum as well. Teacher D saw her students as being relatively active in the learning process by asking questions and providing explanations. She acknowledged that there were instances when students had to be passive receivers of knowledge (i.e., through lectures and presentations), but that she sincerely tried not to allow this to occur on a consistent basis. She recognized the value of having a more student-driven lesson, explicitly described that this type of lesson would involve her students receiving assignments where they have to apply and synthesize their overall knowledge for a particular concept.

Lesson alignment: Teacher B. In Teacher B's classroom, students were receivers of knowledge when she walked her students through various concepts. However, Teacher B's students were welcome to engage her in a thoughtful discussion of the concepts that were being presented. Throughout her instructional unit, Teacher B led five formal presentations and four of them lasted almost (i.e., at least 25 minutes) the entire length of the class meetings. In general, when Teacher B was presenting information during a formal lecture, students were required to take notes. So, students were certainly receiving information in this manner, but student-initiated, content-related questions did occur to some extent. Out of the total teacher-student and student-teacher questions (n=227) that were asked during the course of the instructional unit, Teacher B's students initiated the questions 17% (n=39) of the time. Thoughtful exchanges between Teacher B and her students did take place, which would have allowed her students to begin to construct their own knowledge, but could not be explored further or in-depth because of impending pressure to move on to the next topic.

By Teacher B's definition, opportunities for her students to construct their own knowledge would have primarily occurred through the use of her hands-on activities and other assignments that would have applied their conceptual knowledge. However, the two hands-on activities she had were entirely teacher-constructed and –led. Students were instructed how to proceed and what data to collect. Teacher B's simulation on how speciation occurs had students take the role of individual members of a hypothetical dog population, but Teacher B was the one who determined how the simulation should play out. The students did not have an opportunity to conceptualize a simulation of their own, which would have been evidence of them constructing their own knowledge.

The same sort of actions occurred with Teacher B's simulation on natural selection where students were initially asked to choose a piece of candy from a bowl of assorted wrapped, unwrapped, small, large, and different-flavored candies. Teacher B's students were not told the reason why they were asked to choose a piece of candy until later in the simulation when a student deduced the reason once Teacher B relayed the full contents of the candy bowl. However, instead of the students thinking about how to illustrate the relationship between the class data and natural selection, Teacher B made this determination by explicitly driving the question-answer discourse, analysis of class data, and interpretation of trends. See the excerpt below:

> Teacher B: So pretend you guys are all like islands or little regions within a land area...Which land area would be best for the candies to survive?
> SS: That area. [Students are pointing to the data from the first student group, which has the most "survivors".]
> Teacher B: This one right here, right...because they didn't really eat too much. They had a little bit of something, but the candies are surviving...Which candy is not going to survive?
> [Students call out various candy names.]
> Teacher B: This guy right here, right...[Teacher B refers to the one candy that remains from that specific group's data.] He's not going to survive. There's only one of him left...Which candy did not survive? [Teacher B is still referring to the first group's data.]
> S1: The kisses.
> Teacher B: The Hershey's kisses. The Hershey's kisses are gone...(Class lesson, 4/2/12)

Other exchanges between Teacher B and her students followed this format where Teacher B provided or initiated the set-up of the teacher-student exchange, the students then answered a question from Teacher B, and she followed-up with another question that would lead her students to some resolution on an idea.

Lesson alignment: Teacher D. Teacher D's students were accountable for all the information presented in her formal lectures. However, that is not to say students were not allowed to ask questions. Out of the total teacher-student and student-teacher questions (n=99) asked during Teacher D's formal presentations, the students initiated 22% (n=18) of them. Students asked questions, but Teacher D's presentations were still largely a teacher-driven enterprise with students passively receiving information.

Teacher D occasionally provided opportunities for her students to actively apply their knowledge mainly through some of the assignments (e.g., natural selection candy grab simulation) and daily warm-up questions she required her students to complete. An example of this application of knowledge occurred when Teacher D had the students draw an imaginary creature that exhibited adaptations for its fictitious environment, but the students had to define some vocabulary terms (i.e., *natural selection, fitness,* and *adaptation*) first. Once these terms had been defined, then students could proceed with the remainder of the assignment, which was drawing the imaginary creature:

> Teacher D: You're going to create a fictional creature. It can either be something totally new that no one's ever heard of or if you're having a hard time thinking of something, you can take something that's already existing, but change it…Change it to where it's not how we normally find it in the world today. But, what you're going to do is describe to me…the traits that this creature has. What does it look like? Maybe something physical...maybe it has a certain behavior...explain it to me. And then, explain to me where it lives...what type of environment does it live. (Class lesson, 3/21/12)

The premise of Teacher D's assignment had students apply their knowledge of *adaptations* (maybe not necessarily *natural selection* as a whole). Certainly, the application aspect of the assignment generated questions from several students about their imaginary creature:

> *One student asks Teacher D if he can draw a liger, and she tells him it can't be a liger in the typical sense. Other students ask if they can draw unicorns because they don't exist. Teacher D says they need to draw something else or make some sort of variation of a unicorn. Other students have a hard time thinking about*

> *what to draw and ask Teacher D if they can combine features of different animals to create a fictional creature. Teacher D seems OK with this idea. She also advises students…to think of the environment their creatures will live in, if they're having trouble thinking of a creature to draw. (*Classroom observation notes, 3/21/12)

While Teacher D's students received some opportunities to apply their knowledge, application of evolutionary concepts was not a consistent focus of Teacher D's instructional unit. Many class questions (both verbal and written) were directed towards reinforcement (22%, n=44) and comprehension (32%, n=64) of various concepts, but not necessarily application (< 5%, n=7). Besides the imaginary creature adaptation drawing, the other assignment which included a context where students could apply their knowledge was the aforementioned natural selection candy grab simulation.

Constructors of knowledge. When describing the student role in his lessons, Teacher C was further along the student-centered continuum. He saw his students as constructors of their own knowledge. It may have been his responsibility to facilitate the learning process, but in the end, his students were completely accountable for their learning. He tried to avoid teacher-led presentations at all costs, but would resort to them if he felt his student-centered methods were not obtaining the desirable outcome, i.e., his students learning the accepted scientific conceptions.

Lesson alignment. Teacher C had various assignments dedicated to exploring student ideas (see Table 14), such as the student-generated word clouds and 30-second music videos. However, as mentioned previously, these assignments were not utilized to their fullest potential for exploring student ideas. Word clouds were never shared among the students and the music videos were too open-ended for any useful interpretation. In a preliminary assignment for word cloud creation on Day 4, Teacher C's students had to individually generate a list of 50 terms associated with evolution and justify each term's use. The students, at first, had difficulty getting started, but would be aided when Teacher C verified a term's use and provided justification himself. It is noted that Teacher C exhibited an alternative conception of his own during this interaction when he mentions organisms' "desire to be short":

> S1: Can short be one? Short can be one, right?
> Teacher C: I mean if you're like this big, huge monster. Which one is easier to catch, the bigger one or the smaller one?...It can be an evolutionary trait. So if you're this big huge target or a small target, which one's easier to get? Probably the bigger one, right? So maybe there is desire to be short in certain organisTeacher..certain creatures. (Class lesson, Day 4, 3/30/12)

As seen from this brief exchange, Teacher C confirmed the use of "short" and provided the reason why it could be included on S1's list by stating small size could be advantageous trait in order to evade a predator. However, as opposed to having S1 provide the justification by asking follow-up questions, Teacher C answered his own rhetorical questions. This sort of interaction was typical with many students. The students continued to brainstorm, asked Teacher C for his approval of many terms, and he would then provide the justification.

Summary. According to all four teachers, their preferred ways of learning science had a significant influence on how they taught biology. However, this degree of influence revealed some intricateness. For example, Teacher A admitted some conflict with how much her perception had an influence because she knew her students learned best when they participated in differentiated sorts of activities, such as scientific investigation and experimentation. However, she felt her students did not have strong enough content knowledge to participate fully in the inquiry process. That is, the time constraints and demands of the biology curricular schedule did not allow her to plan adequately and prepare her students for true inquiry in her classroom. As a result, Teacher A frequently found herself resorting to the methods of instruction with which she was very familiar:

> …There's no doubt it does influence my teaching. I mean, there's that and...part of it's organization 'cause I would love to be able [to do]...inquiry sort of thing...but there's so much stuff...I mean they have no background knowledge of that. If I really do pure inquiry, they're going to be lost and I'm going to be jumping in and backtracking, especially with this class this year…So I mean my teaching style...my learning style influences my teaching. I wish it didn't have to influence so much, but it goes hand in hand with the time frame involved. (Post-instruction interview, 4/25/12)

Teachers A, B, and D had specific practical visions for what a teacher's place was in a science lesson (see Table 15's summary). However, Teacher C approached the description from a more student-centered perspective. In Teacher A's vision, a science teacher determined the classroom climate and almost all activity that took place. There was room for student input, but not much. This was in somewhat of a contrast to Teacher B and D's visions of a more balanced approach between teacher- and student-centeredness. They knew they had to provide information to their students, but did not want to be the only ones engaged in the subject matter. They articulated different reasons for this approach (Teacher B wanted to make the concepts less abstract and more familiar; Teacher D knew more student-centered lessons would have longer-lasting conceptual understanding effects), and ultimately settled on a teacher being responsible for differentiated instruction. An anomaly within this group, Teacher C's description of mentally preparing students suggested a vast openness to various ideas and instructional strategies, that is, using whatever worked to engage his students.

Teacher	Teacher role	Consistent alignment with lessons?	Ideal science lesson	Consistent alignment with lessons?	Student role	Consistent alignment with lessons?
Teacher A	provide information	Yes	following specific sequence: engagement activity, teacher-led lecture, student-led investigation	No	“actively” receive knowledge	No—“passively” receiving knowledge
Teacher B	make scientific concepts less abstract	Somewhat	following specific sequence: teacher-led lecture, student-led investigation, closure with assessment	No	receive and construct scientific knowledge	No
Teacher D	balance between providing information and having students do intellectual work	No	following specific sequence: review previous lesson concepts, engagement activity, teacher-led lecture, student-led investigation	No	receive and construct scientific knowledge	No
Teacher C	“mentally prepare” students for learning	Somewhat	students discussing scientific ideas while working with hands-on activities	No	construct scientific knowledge	Somewhat

Table 15: Summary of findings regarding teachers’ self-professed science teaching orientation and alignment with lessons on evolution.

Teachers B, C, and D were all well aware that their students required a differentiated approach when learning scientific concepts--despite Teachers C and D’s self-described perception of learning science through listening to lectures and/or reading information (Teacher D stated not many of her students approached learning science in this manner). Teacher C, in particular, strove to emulate his undergraduate (science) and graduate (education) course instructors, who incorporated a variety of methods and strategies when teaching. Therefore, while Teacher B was completely influenced by her perception as a science learner when teaching biology, Teachers C and D were somewhat less so. Even though they preferred to absorb information, they both always saw themselves reaching out to differentiated approaches that usually augmented their understanding of scientific concepts when teaching.

Teachers C, B, D, and A, to some extent, all mentioned hands-on activities as being an integral part of their ideal science lesson. Every teacher also expressed disdain for their current 45-minute class period schedules, in that there simply was not enough time to incorporate as many hands-on activities as they would like into their science lessons. On many occasions, Teacher B felt she had to prematurely end students' natural curiosity and inquisitiveness on one topic because of the pressure to move on to the next topic. She felt her students could benefit from a more relaxed setting where they felt free to explore different ideas and questions.

Research Question #1B: Does a group of biology teachers' self-professed orientations to evolutionary theory align with lesson implementation?

Similar to science teaching orientation, a teacher's attitude and view of a particular topic can have an impact and influence their curricular and instructional decisions (Carlsen, 1991; Grossman, 1990; Hashweh, 2005; Friedrichsen et al., 2011). Therefore, a biology teacher's view of evolutionary theory as a scientifically valid explanation can have potential importance in the place evolution has in the biology curriculum (Rutledge & Mitchell, 2002; Berkman & Plutzer, 2011). Before each teacher's instructional unit began, his/her orientation towards evolution was gauged with their responses to: 1) whether or not they accepted evolutionary theory and had any issues with teaching it; 2) the purposes and goals of their individual units; and when warranted, 3) the rationale for those purposes and goals. The teachers' results are provided below.

Similar to alignment with science teaching orientation, every teacher's alignment of his/her lessons with his/her respective orientation to evolution was examined through the use of his/her implemented instructional activities, which were previously seen in Table 14. Each teacher's lessons, with respect to topic, teacher discourse, and types of assignments, were coded (see coding scheme in Appendix E) according to each teacher's emergent themes regarding orientation to evolution. If the majority of a teacher's lessons ($\geq$ 5 or 6) were consistent with his/her themes from the evolutionary orientation constructs mentioned above, then alignment was confirmed.

Acceptance of evolutionary theory: Complete acceptance or ambivalence. Personally, all four teachers accepted evolutionary theory and had no issues with teaching it. However, upon closer examination acceptance issues began to emerge with one of the teachers. From the beginning, Teacher C did not have any issue with teaching evolution and accepted the basic tenets of evolutionary theory. However, upon further questioning Teacher C revealed ambivalence with his evolutionary acceptance. He enjoyed learning and reading about scientific and evolutionary concepts, but admitted conflict with his personal spirituality (as if science and religion were in dichotomous opposition):

> So, I do accept both [science and religion], but I am so…so overwhelmed with science and I'm such like a science freak that…I have a strong grasp on what I already do know what is the physical and concrete evidence versus my spiritual side. So, granted, I still know that I have…I know I feel spirit, like some sort of spirituality in me. You can feel it inside your body. But, how is that related to science? I have no idea how. And, how can I explain it? I still can't. (Pre-instruction interview, 3/27/12)

Teacher C stated he had difficulty, specifically, with understanding the initial impetus that propelled evolution because of a lack of evidence from his perspective. He said, "But, to really understand like what's truly at stake of the whole what drives all of evolution…I think that mostly everybody has no clue, you know, what's going on…It's hard to see any evidence from the very beginning…from a point of origin…and then, that's pretty much where…you run into a lot of conflict with the whole religion idea in evolution" (Pre-instruction interview, 3/27/12).

Lesson alignment: Teachers A, B, & D's complete acceptance. As mentioned previously, Teachers A, B, and D accepted evolution as a fact and had no issues with teaching its concepts. While all three knew the topic was controversial for some students, they believed it was their responsibility as science teachers to "teach the science" and not necessarily dwell on the religious aspects to which evolutionary theory is linked. No mention of religion was ever made by either Teacher D or her students during the instructional unit. For Teacher A, conversations on the topic of the controversy between evolutionary theory and religion were all relegated to taking place outside official class time.

However, in Teacher B's case, she felt she had to also acknowledge the science vs. religion debate that seemed to confuse students at times. She formally acknowledged the controversy once during her instructional unit while her students were watching the video, "What Darwin Never Knew":

> Teacher B: This is where the controversy in evolution takes place. The [Christian] religious belief is that all of us were born perfect, exact to what we are. But Darwin had all this support and backup...scientific explanations on how we are actually different and how we've evolved to become what we are. So it was a big controversy at the time. Even today, it's still a big, big controversy. In fact, there's many religious people who do not like us teaching evolution, but it's part of science. I'm not here to change your mind on evolution, whether you believe it or not. I'm just here to show you guys the evidence to support it.
> S1: Miss, do you believe in God?
> Teacher B: So whatever your all's beliefs are...I believe in God too, but I do believe in evolution.
> [Various inaudible student chatter...]
> S2: Why is there a problem with all the religious people?
> Teacher B: Because in the Bible...literally taken...when you read the Bible it says that we were all created...to what we are today...that we are the exact image of

> what we were created as. But if you look at evolution, that's not true and there's a lot of evidence to support it...So that is one reason why they don't like us teaching evolution because it does contradict what the Bible says...
> S3: We're supposed to separate school from...
> Teacher B: From religion...But it's hard to do it with evolution...So we're [as teachers] not here to change your mind, religious-wise...But I do have to present the facts to you...(Class lesson, 3/27/12)

From this exchange between Teacher B and some of her students, it appeared that some students may have been unaware that such a controversy existed (see S2's comment above). Nevertheless, this exchange was emblematic of Teacher B's personal and pedagogical orientations towards evolutionary theory, where scientific evidence would take precedence in her classroom, but acknowledgement of students' personal beliefs needed to occur early on in her instructional unit so that her students would maintain an open mind to evolutionary concepts.

Lesson alignment: Teacher C's ambivalence. Despite Teacher C's claims of not wanting to impart his values and thinking of evolution on his students, there were several instances during his instructional unit when his ambivalence towards evolutionary theory became apparent. Teacher C's issue with evolution came from trying to understand the process at the molecular level, which partially explained why he would refer his students back to DNA-focused structure and processes. Specifically, Teacher C often questioned if there was some sort of outside molecular force causing mutations to occur in DNA sequences, thus driving evolution forward. Since Teacher C, himself, questioned the process he believed his students should question it as well:

> But, the one thing that when I do…do that…just showing them how DNA does that…doesn't really show them how DNA gets its motive. And that's one thing a lot of people still don't even know. You know…I mean…we say it's energy-driven and there's a lot of other…influences. So, I want them to actually kind of wrap their brain around that…there is something smaller in there and there is

> something that drives that smaller thing. I want them to kind of stop and think, "What is it that drives it and why?" (Pre-instruction interview, 3/27/12)

While Teacher C did not have specific assignments for his students that targeted this "motive" for evolution, he did have a specific video (which the observed class never saw) that addressed the topic and the issue was formally discussed on two separate occasions during the instructional unit. When this issue was discussed, Teacher C initiated all questions. Here is an example of one such sequence:

> Teacher C: DNA...has a lot of information, right? And it possesses a lot of information that can even pass on successful information to the next generation. But my question to you guys is...look at it [has students look up at DNA models pasted to the ceiling]...Phosphate, a sugar, a nitrogen base pair...My question is how do they know how to work together? How did they even come about...figuring out, "Oh, yeah...Let's all come together"…What drives them? That's the question...What drives them? What drives DNA? What drives it?
> S1: Their ancestors.
> Teacher C: What drives it?
> S2: To find better...To get better.
> Teacher C: They're made out of individual compounds. They're made out of elements, right? What have you guys been taught about elements? One single element is composed of what three things?
> SS: Protons, neutrons, electrons...
> Teacher C: What controls them?
> S3: The nucleus.
> Teacher C: What possesses those things to have? What do they possess?
> S1: There's a certain amount.
> S4: Energy?
> Teacher C: Energy...All this stuff is energy-driven...Now how does it work? I don't know. (Class lesson, Day 5, 4/3/12)

At first, Teacher C's students did not quite know how to respond to his line of questioning, perhaps indicating they, themselves, never thought of DNA as possessing some sort of "drive". It was not until Teacher C related the drive of DNA to the nucleus of an atom that the students seemed to understand the point Teacher C was trying to make.

Goals for students when learning evolutionary theory. All teachers enumerated several learning goals for their students during their instructional units on evolution. The teachers' goal descriptions provided insight and perspective with how the teachers approached their individual instructional units.

Evolution is not "just a theory" and is supported with scientific evidence. Both Teachers A and D wanted their students to have a better, overall understanding of the nature of evolution as a strong theory in science, whether in terms of emphasizing the research that continues to support it or the nature of evolutionary theory itself. Teacher A felt her students never really had a true grasp of all the scientific evidence that supports evolution:

> So I wanted to try to get to that point…so they could see other people talking about it and look...this is the science behind it. It's not just stuff that we pulled out of the air...I think it just helps with the acceptance. It's like, "Oh, OK. There's all this weird stuff going on and they're constantly researching it and it's still sticking to the plan." I think [the students] think, "Oh, it's a big idea" and they don't realize how many changes have happened...how much research has been done...and just proving it over and over again. And so, I don't think they grasp how much has gone into the theory of evolution...and how Darwin was just the beginning...(Daily interview, 3/29/12)

Like Teacher A, Teacher D believed it was her responsibility to teach evolutionary concepts solely and not acknowledge any sort of science vs. religion controversy. They both wanted to avoid any religious aspects and "stick to the science."

Lesson alignment: Teacher A. Teacher A was adamant about her students seeing different ways in which evolution was researched and studied so that they would understand that evolution was not "just a theory". This was one of the main reasons for devoting substantial time (almost three class meetings) to the video, "What Darwin Never Knew". With its relatively recent (the video was released in 2009) explanation of popular advances in evolutionary research, Teacher A believed exposure to these ideas would address the alternative conception that the idea of evolution began with Charles Darwin alone and ended when he died. Another way in which Teacher A tried to incorporate this goal into her unit was with her oral account of how a population of Hawaiian crickets was evolving. The account presented the effects and ramifications from recent research and scientific evidence detailing how a group of crickets' chirping was becoming quieter on one of the Hawaiian islands. For the most part, Teacher A's lessons were somewhat aligned with the goal of her students being aware of the scientific evidence supporting evolution by having some of her lessons (n=4) incorporating this overall theme.

Lesson alignment: Teacher D. Teacher D took a different approach to emphasizing evolution's nature as a scientific theory. She presented evolution's evidence as it was, with no further support from current research and would attempt to integrate NOS concepts during her unit, especially towards the beginning. On the first day of her unit, when introducing evolution to her students, Teacher D asked her students to differentiate between a theory and a hypothesis:

> Teacher D: But, an important thing you need to know is what is a theory. When I say theory of evolution, what's a theory? A theory means that it's a hypothesis that has a lot of evidence to support it and he [Darwin] collected a lot of that evidence. So, a lot of evidence to support a hypothesis makes a theory...What's a hypothesis again?
> S1: A prediction?
> Teacher D: Prediction...educated guess...right. He had an educated guess and it's supported by a lot, a lot, a lot of evidence...not just a little bit of evidence, but **a lot** [emphasis added] of evidence to help support his...guess. So that's what a theory is. (Class lesson, Day 1, 3/19/12)

Two similar teacher-student exchanges occurred during the course of Teacher D's unit, one taking place on Day 1 of her unit and the other on Day 5. Here is Day 1's additional exchange:

Teacher D: OK. So, throughout this voyage, this five-year voyage that he went on, they went to many different countries, different continents and he made many, many observations. What's an observation? When I say observation, what does that mean?
S1: Studies...
Teacher D: Studies...like looking at something, right? Observing it...So, he would observe animals, observe different types of species and he would write down what he saw. He also collected different species throughout his travels. So, like, from one area he collected not just one type of beetle, but he collected 68 different types of beetles. And he kind of observed and examined how they were different. OK...So, that's one thing he did. (Class lesson, Day 1, 3/19/12)

Here is the exchange that took place on Day 5:

Teacher D: Again, who proposed the theory of evolution?
S1: Darwin?
Teacher D: Darwin. And...what is a theory? What does that mean?
S1: Like...what he thinks...happened.
Teacher D: So it's a hypothesis. But, not only is it a hypothesis…
S1: It has evidence.
Teacher D: It has evidence. It has a lot of evidence to support it. (Class lesson, Day 5, 3/28/12)

Teacher D never implemented instructional activities that were actually designed around NOS concepts. Her emphasis on NOS was always through various interactions while she was asking questions of her students. However, the three exchanges presented above were the only substantial interactions that dealt with NOS.

Certain evolutionary concepts and vocabulary need to be emphasized. There were specific concepts all teachers wanted to be sure they emphasized during their instructional units: 1) populations evolve, not individuals (Teacher A); 2) evolution takes time to occur (Teachers A & C); 3) common ancestry (Teachers B & D). Teacher C also wanted his students to relate to how evolution occurred in other organisms besides humans; that is, de-emphasizing the human-centric view of evolution. In addition to understanding the big ideas of evolution, Teacher D believed vocabulary terms were necessary to understanding the nuances of evolution.

Lesson alignment: Teacher A—emphasis on populations evolving, not individuals. Before her instructional unit began, Teacher A believed the common alternative conception of individuals evolving needed to be addressed. As a result, she devoted an entire presentation to the evolution of populations, where she described the concept of a *population* by using various examples with which students were familiar, such as different groups of animal species found within the local environment. Also during this lesson, Teacher A had her students interpret graphical forms of population data from the textbook to further support the idea that entire populations evolve, and not individuals. For more emphasis, Teacher A had her students participate in a simulation that demonstrated a population of drift worms evolving (through the genetic drift mechanism) by rolling a die and determining the outcomes of their traits.

Teacher A's incidental language throughout her instructional unit also reflected this goal. On a variety of concepts that may not have appeared to be directly related to how populations evolve, (e.g., *origin of variation, differential survival, inheritable variation*), Teacher A was consistent in the use of her terminology (i.e., referring to populations when singling out hypothetical individuals for their traits, discussing the genetic variety of individuals within populations).

Lesson alignment: Teachers A & C—emphasis on evolution taking time. Teacher A believed her students failed to appreciate the amount of time involved for evolution to take place. While Teacher A did not specifically mention deep time frameworks (e.g., references to billions and millions of years ago) during her instructional unit, she made a deliberate effort to always refer to evolution as “change over time” and whenever her students were asked to define evolution, they needed to always define it as “change over time.” When specifically mentioning how long it would take for evolution to occur in a population of mice, for example, Teacher A would describe the process in terms of generations (e.g., 13 or 14 generations) as opposed to some amount of years. However, it should be noted that Teacher A’s use of “13 or 14 generations” as a typical example of the length of an evolutionary process possibly promotes a misconception that 13 or 14 generations is a substantially long time in terms of how long it takes macroevolutionary processes to occur.

In a similar fashion, Teacher C believed his students needed to have a better understanding of the amount of time it took for evolution to occur. In this effort, he showed two different introductory videos (see Table 14 earlier in this chapter) to his students at the beginning of his unit. The first video depicted major evolutionary events, e.g., the transition of marine populations to land environments, in an animated format and the second video depicted major geographic and planetary events, e.g. the formation of continents. While the videos did not specifically address time spent with evolutionary processes, Teacher C would tell his students, beforehand, to be mindful of the number of years it took for the depicted events to occur:

> *Teacher C emphasizes the importance of time with his introduction of evolution, in that the typical human life span is rather insignificant when considering how long evolution takes to occur. Teacher C wants his students to pay particular attention to the time frame the video's events depict. He challenges his students to think of the time frame and to write the range somewhere in their notebooks. As opposed to writing shorthand numbers, like "10 billion" for example, Teacher C wants for them to write out the entire number.* (Class observation, Day 1, 3/28/12)

Instances similar to the above description occurred three more times during Teacher C's first day of evolutionary instruction, with Teacher C pausing the videos intermittently to remind his students of the time associated with evolutionary processes. The videos continued on Day 2 and 3 of the unit, with Teacher C reminding his students three additional times (twice on Day 2 and once on Day 3) of the time involved with evolution.

Lesson alignment: Teachers B & D--emphasis on common ancestry through similar genes. Before their respective instructional units began, Teachers B and D believed the big idea of *organisms evolving from a common ancestor* needed to come across to their students during their instructional units. From this idea, both teachers wanted to make their students aware of the specific genetic evidence that supported common ancestry. As a result, both teachers attempted to integrate the overall idea of common ancestry throughout their instructional units, and not simply with single, isolated lessons devoted to this concept.

For Teacher B, however, the concept of common ancestry appeared and was emphasized only five times during the entire unit with teacher-student discourse. It was apparent with two distinct teacher-student discussions (ranging from 8-16 teacher-student exchanges) during her lessons on evidence for evolution (Days 4-5) and with three distinct teacher-student discussions (ranging from 5-8 teacher-student exchanges) during the whole-class review at the end of the unit (Day 10), but was not a common thread throughout the unit. Of these five discussions, only one stressed common ancestry with genetic evidence and this interaction occurred during the whole-class review (Day 10). Three separate questions on the topic of common ancestry appeared on two different sets of multiple choice warm-up questions (Days 6-7) and on the whole-class review ("How does the evidence presented for evolution help in identifying organisms being related to each other or coming from a common ancestor?" Day 10, 4/10/12).

From analyzing Teacher D's recorded lessons, the concept of common ancestry appeared and was mentioned and emphasized in various forms during the entire unit, especially when the focus of her lessons shifted towards evidence for evolution (similar to Teacher B). However, the occasions in which *common ancestry* appeared did not always involve teacher-student discourse. These particular instances had Teacher D use *common ancestry* as more incidental language during various lessons. Nevertheless, when discourse was involved (approximately 10 instances), the teacher-student interactions would center on a concept and then have Teacher D ask of its support and meaning for evolution, eventually settling to genetic relatedness and common ancestry:

> Teacher D: OK…What do all these things tell us? Why does it let us know that there's support for evolution?
> S1: 'Cause like it gives it more proof?
> Teacher D: How? What does it show us?
> S2: That we have some things in common so we must come from (*inaudible dialogue*).
> Teacher D: Exactly. We have things in common so we must come from a common ancestor. (Class lesson, 3/30/12)

Common ancestry's link with genetic concepts occurred less frequently throughout Teacher D's unit, but was made more apparent when the topic centered on natural selection and adaptations. Of the aforementioned *common ancestry* discourse instances (n=10), half of those involved genetics concepts (e.g., mutations being a source of genetic variation).

Lesson alignment: Teacher C—de-emphasizing human-centric view of evolution. Teacher C believed his students had a human-centric approach to understanding evolution. He wanted his students to understand evolution from the perspective of other organisms His more traditional assignments (i.e., worksheets) reflected this purpose, with several different scenarios involving populations of plants and other animals. He would also directly tell his students to imagine evolutionary processes from another organism's point-of-view. Teacher C emphasized this different perspective during the final days (Days 8-10) of his unit, particularly when he was leading his students through formal lectures on different evolutionary concepts. This teacher-student interaction is an example of how Teacher C would emphasize the different/other organism perspective:

> Teacher C: Are you guys a population?
> SS: Yes.
> Teacher C: Population of what?
> S1: Humans.
> Teacher C: Humans...Give me an example of a different population.
> S2: Chickens.
> Teacher C: Chickens...apes...You guys are starting to get the idea. When I think of populations, I don't think of just humans. I think of biologically...I think of other organisTeacher (Class lesson, Day 10, 4/11/12)

When S1 answered "humans", Teacher C directed the class to give him an alternate example of a population (S2's answer of "chickens"). The quick response from S2 may have occurred since Teacher C had instructed his students before (on Days 8 and 9) to think from a new perspective.

Lesson alignment: Teacher D—emphasis on key vocabulary. Before her instructional unit began, Teacher D believed key vocabulary terms needed to be emphasized mainly so that her students would have more familiarity with the terms. More familiarity would place them in a proactive position for when other evolutionary concepts were introduced. Other than *natural selection* and *genetic drift,* Teacher D did not specifically mention which other terms were of importance. However, a more comprehensive idea was received from the actual vocabulary assignment her students were required to complete. The assignment included 17 terms the students were to define, along with creating a picture, sentence, or example to accompany the definition. Some of these terms seemed essential to Teacher D, as evidenced by her use of them in multiple ways in her lessons (see Figure 9 below) (i.e., presentations, daily reviews, worksheets, other assignments). These essential terms included *evolution, theory, fitness, fossil, natural selection, artificial selection, survival of the fittest,* and *adaptation.*

Mission Countdown:

1. **Define Natural Selection:**

2. **True or False: Darwin believed all living organisms come from a common ancestor.**

3. **What is meant by "Struggle for existence"?**

4. **Define Adaptation and give an example.**

Figure 9: Example of Teacher D's daily warm-up (review) questions from Day 3 (3/21/12).

Compartmentalization of concepts. Lastly, Teacher A stressed the idea of wanting her students to "compartmentalize" evolutionary concepts. To Teacher A, this meant students would develop a firm grasp on basic concepts and then proceed to understand how these concepts are related to one another. According to Teacher A, approaching her instruction in this manner would possibly assuage any issues students had with accepting evolution.

> …and they can take evolution and try to compartmentalize it if they need to…and that's what I try to…promote for those that are very standoff-ish about it...I'm like, "Well, can you at least see it in these terms? Can you see that there's been change over time?" So, I try to use…smaller examples. (Pre-instruction interview, 3/9/12)

Lesson alignment. In a general sense, Teacher A's topics were taught separately and distinctly. As was consistent with her goals for her instructional unit, this was the approach she favored taking. For example, *evidence for evolution* was distinct from *natural selection,* as was *evolution of populations*. Within each general topic, each sub-concept was also addressed separately and re-emphasized upon review. For example, within natural selection some of the concepts Teacher A addressed separately were *adaptations, fitness,* and *struggle for existence*. When her students received warm-up and review questions after learning about these concepts, the questions addressed each concept separately (e.g., "What is fitness?" "What's an example of an adaptation?"). There were never any activities or assignments that asked the students to synthesize the different concepts of a general idea.

Retain openness to alternate ideas. Teacher C felt unsure about the evidence that supported evolution. Therefore, he wanted his students to remain open to alternate ideas that might explain evolution. Teacher C emphatically believed it was not his place to influence his students' ideas one way or another:

> I want them to be open to alternate ideas. So that way, they can truly build their own ground basis of what they feel like is the truth and what is not the truth. I feel that it's important that they know that there's alternate ideas and it's not just set one way in stone because it's just a theory. I mean...it's not even correctly fully proven. (Daily interview, 4/9/12)

The alternate ideas of which Teacher C spoke stemmed from his own ambivalence towards evolution, but he believed himself to be truly emulating his university professors by asking questions like, "Where did we come from?" and giving his students pause to think about life's origins in general.

Lesson alignment. Teacher C's goal of wanting his students to retain an open mind to other ideas other than evolution stemmed from his understanding that evolution was "just a theory" and had not been "fully proven". This openness to alternate ideas was an underlying theme in Teacher C's unit, especially when he showed his class different representations of evolution through various short videos on Day 5 of his unit. On this particular day, Teacher C had every intention of showing the observed class a video on intelligent design as one of the representations, but Teacher C lost track of time and never showed it to this group of students (although his other biology classes did see the video). On the final day of his unit, as Teacher C was leading his class through a presentation of natural selection, he made it known that he remained skeptical about Darwin's theory, and that his students should be as well:

> Teacher C: 'Cause Darwin is now saying, "No, no, no, no...Things didn't evolve because they wanted to. Things evolved because nature started picking on certain ones." And the ones that were more fit ended up surviving...
> S1: And he was right?
> Teacher C: Well, it's still a theory. There's still the theory of gravity. Gravity is still a theory.
> S1: There's just different theories, huh? Like...
> Teacher C: There's just...I mean it's a theory. You can actually disprove it so far...if you could. I mean that's why it's a theory. So until somebody disproves him, it's still a theory.
> S2: Wait...OK...Why is it not a fact yet?
> Teacher C: 'Cause it's just a theory. So far it's right, but until somebody proves it wrong, then it's still going to be a theory.
> S3: Why is his the most popular?
> Teacher C: Why is his the most popular? 'Cause so far, if the shoe fits, wear it, right? So far, everything he's been saying has been kind of suited for it. Now is he right? We don't know that. That's why it's still a theory. Is there other alternate ideas? I try to express some...from other professors, people that have spent a lifetime on this. Just so that way you guys can see different perspectives on this. I [don't] want you guys just wrapped around "This is it...this is it in concrete". 'Cause it's not it. It's not it in concrete. (Class lesson, Day 10, 4/11/12)

Teacher C's other formal assignments did not necessarily reflect this skepticism. This goal of his students keeping an open mind was apparent just through various teacher-student discourse and Teacher C's choice of instructional strategies.

Summary. It was important to gauge each teacher's thoughts and feelings about evolution before instruction formally began so that any relationship between the teachers' personal beliefs on evolution and their subsequent instruction could be determined. Every teacher initially accepted evolution at the onset of their individual instructional units. However, issues with acceptance began to arise with Teacher C once he was further probed. With the single exception of Teacher B's initial acknowledgement of the evolution controversy to her students at the beginning of her unit, Teacher C's three other colleagues relegated any discussion of religion and creationism to the time outside of class. Their instructional activities and strategies consistently aligned with their personal acceptance of evolution (see Table 16), in that they believed the science of evolution needed to be explained. As a result, many of their classes focused on the explanation of evolutionary concepts and the evidence for evolution.

Teacher	Acceptance of Evolutionary Theory?	Consistent Alignment with Lessons?	Purposes and Goals of Instructional Unit	Consistent Alignment with Lessons?
Teacher A	Yes	Yes	Scientific evidence supports evolution	Somewhat
			Populations evolve, not individuals	No--Isolated
			Evolution takes time to occur	Somewhat
			Compartmentalize concepts	Yes
Teacher B	Yes	Yes	Organisms evolve from a common ancestor	No--Isolated
Teacher D	Yes	Yes	Evolution's nature as a scientific theory	No--Isolated
			Organisms evolve from	Yes

			a common ancestor	
			Emphasize key vocabulary	Yes
Teacher C	Ambivalent	Somewhat	Evolution takes time to occur	No--Isolated
			De-emphasize human-centric way of thinking	No--Isolated
			Remain open to alternate ideas that may explain evolution	Somewhat

Table 16: Summary of each teacher's orientation to evolution and its alignment to his/her lessons.

One might say that Teacher C had consistent alignment as well, in spite of his misgivings about certain aspects of evolution. Aside from focusing on specific concepts (discussed below), he wanted his students to remain open to other explanations for how evolution occurs. This goal Teacher C described was most likely an extension from his own personal conflicts with evolution and he believed his students needed to question the science as much as he did. While the science of evolution was certainly presented to his students, Teacher C usually cast the science in a doubtful light and always made his students aware of the other options that existed, even if they were non-scientific (although he never mentioned to his students these options were non-scientific).

Along with personal goals for their instructional units, the teachers described certain "big" ideas they wanted to make sure their students understood. These ideas were examined for consistent use throughout each teacher's instructional unit. The results revealed some inconsistency across the teachers' "big" ideas, which included *scientific evidence supporting evolution, populations evolving and not individuals, evolution taking time to occur,* and *organisms evolving from a common ancestor*. Some ideas occurred in isolation, with one or two lessons devoted to their concepts; whereas other ideas maintained a constant presence with the teachers making frequent mention and referring back to them. The ideas that occurred in isolation tended to be more specific (e.g., populations evolve, not individuals) than the others that were more global in nature (e.g., scientific evidence supports evolution). These results suggest the teachers may not often receive opportunities to think about the big ideas of an instructional unit and resolve to describe specific ideas and concepts--although vital to any instruction on evolution--around which are difficult to plan an entire unit.

Research Question #2: Aided by the use of a concept inventory, what is the nature of the teachers' *knowledge of their students' alternative conceptions* with regards to natural selection (Anderson et al., 2002), specifically? How does the teachers' elicitation of students' evolutionary alternative conceptions inform their teaching practices?

Being familiar with evolution's alternative conceptions can be a potentially powerful tool in understanding the learning difficulties associated with this topic and serves to enhance a teacher's PCK by enabling teachers to better understand student thoughts and ideas (Magnusson et al., 1999). In addition, students' alternative conceptions can serve to guide lesson planning and instruction if utilized by teachers in some fashion (Scott et al., 2007). In the current study's context, each teacher was formally made aware of his/her students' alternative conceptions by using the CINS before evolutionary instruction began. The results from each teacher's students was analyzed and synthesized into an overall report that relayed general trends for how his/her students answered each question on the CINS. Each teacher received a copy of his/her "student results report" (see Figure 8 in Chapter 5) approximately 3-5 class days before each teacher's instructional unit began. In order to answer this research question, multiple data sources were analyzed, which included each teacher's: 1) responses to specific pre-/post-instruction and daily interview questions, 2) prediction accuracy of his/her students' alternative conceptions, and 3) video/classroom observations.

Value of students' knowledge and alternative conceptions. When asked about how their students' knowledge informed their practices, all the teachers spoke in terms of their students' *prior* knowledge. In order to form a distinction between their students' prior and currently-acquired knowledge (and how this type of knowledge informed their practices), all the teachers were also asked to describe if and how they changed instructional plans "on the fly". Initially, Teachers B, C, and D all spoke of familiarity with students' knowledge and alternative conceptions as an advantage in their individual practices. Whether this knowledge was in the form of specific, concrete ideas or skills their students possessed, these three teachers said they used this knowledge to certainly help plan their lessons. Teacher A, however, learned that she could not "count on" her students possessing any sort of prior knowledge on most topics. This may also help explain Teacher A's science teaching orientation as a dispenser of information (see results for research question #1A).

All four teachers commented on the need to be flexible when it came to using student knowledge or actions as a means to inform their decision-making. Teachers A, B, and D often cited lack of student participation in various activities as a signal that their students were having difficulty with the subject matter. In these cases, all three teachers mentioned experiences where each had to revise a class activity entirely and/or adjust for later classes in the day:

> In certain classes I can fly through the stuff, no problems. Other classes, it's like they're…just pulling teeth. So, I have to re-assess my strategy and maybe try something a little different to help them understand it. So, yeah…I wind up doing it like, "OK. This isn't working. Let's try this. OK. *This* isn't working. Let's try this." So, I've used the little white boards and said, "OK. You guys aren't getting it here. Let's all use the white boards. We're all going to do this." Or, I'll take away the white boards 'cause they're not working and I'll have more of a guided thing, "OK. So, if we had this, this, and this, what's going to happen here?" So, it's more guided. Or, I'll have them group together and say, "OK. You guys are going to help each other…I'm gonna walk around." So, depends on the situation, but…yeah, I've gotten really good at doing that stuff on the fly. (Teacher B, Pre-instruction interview, 3/20/12)

Teacher C mentioned he altered lesson plans on the fly as well, but mostly did it as a response to his students' lack of preparedness at times. According to Teacher C, changing plans in response to lack of student understanding was done on a case by case basis, and did not always affect the way he ran subsequent classes.

All four teachers described different instructional strategies for gauging their students' alternative conceptions and knowledge on different topics. No single teacher used a formal pre-assessment (like the CINS) at the onset of any instructional unit. The most popular strategy to gauge student ideas was informal questioning, usually in the form of a quick whole-class discussion:

> 'Cause, I mean, mostly…your initial assessment is like when you first start talking and asking questions…that's mostly my assessment. When I first introduce it, it's like, "OK…What do you know about that? Oh, okay." And then you see the questions that come at you and…what they do recognize and what they don't recognize and then you get an idea. Very informal though…(Teacher A, Pre-instruction interview, 3/9/12)

It should be noted that informal questioning was not limited to the beginning of an instructional unit. All four teachers said this form of assessment was continuous throughout the duration of any unit. Other instructional strategies included the major projects students turned in (Teacher C) and written multiple-choice/short answer assessments (Teacher D). Teacher B also described using information gathered from district-written assessments as a way to inform her lesson planning and realize which topics or concepts with which her students needed to spend more time.

Accuracy with students' natural selection alternative conceptions. Before any of their students were initially assessed with the CINS (as a pre-test), all four teachers were asked to predict their students' most common alternative conceptions. These predictions were then compared to their students' actual answers (for a summary of correct student pre-test responses by teacher, see Table 17). The teachers' individual prediction accuracy scores are reported in Table 18.

	Concept	Teacher A	Teacher B	Teacher C	Teacher D	Average
#1	Biotic Potential	69%	42%	67%	57%	59%
#11	Biotic Potential	48%	27%	54%	49%	45%
#2	Natural Resources	51%	62%	53%	60%	57%
#14	Natural Resources	29%	23%	33%	21%	27%
#3	Population Stability	71%	67%	63%	58%	65%
#12	Population Stability	25%	19%	31%	23%	25%
#4	Change in a Population	29%	26%	22%	21%	25%
#13	Change in a Population	36%	31%	25%	21%	28%
#5	Limited Survival	39%	26%	40%	38%	36%
#15	Limited Survival	20%	22%	28%	27%	24%
#6	Origin of Variation	14%	11%	9%	11%	11%
#19	Origin of Variation	44%	31%	40%	26%	35%
#7	Inheritable Variation	68%	62%	56%	51%	59%
#17	Inheritable Variation	53%	46%	42%	28%	42%
#8	Origin of Species	35%	46%	37%	29%	37%
#20	Origin of Species	28%	25%	24%	20%	24%
#9	Variation w/in a Population	43%	38%	41%	38%	40%
#16	Variation w/in a Population	66%	49%	78%	51%	61%
#10	Differential Survival	10%	17%	17%	12%	14%
#18	Differential Survival	14%	15%	19%	15%	16%
Avg. # of Student Respondents on Pre-Test		83	81	80	81	

Table 17: Percentage of student correct responses on CINS pre-test grouped according to each teacher.

TEACHER	NO. OF TOTAL QUESTIONS (N=20) COUNTED TOWARD PREDICTION ACCURACY MEASURE	TOTAL PREDICTION ACCURACY (CORRECT & INCORRECT QUESTIONS)
TEACHER A	17	0.90 (SD=.19)
TEACHER B	18	0.74 (SD=.27)
TEACHER C	19	0.87 (SD=.20)
TEACHER D	20	0.82 (SD=.22)

Table 18: Teachers' prediction accuracies of their student alternative conceptions on the CINS for number of **total** questions answered by teachers.

Table 18 is a summary of results when all questions are taken into account (with the exception of those questions which had no predictions for alternative conceptions). Overall, the results seen here seemed to reveal some consistency across these teachers' total prediction accuracy scores. A comparison of all the teachers' prediction accuracy scores revealed no statistical significance with a one-way ANOVA, verifying the consistency with which these teachers predicted their students' alternative conceptions.

When considering all the CINS concepts (from averaging both questions on each concept and teachers' total responses) answered by this group of teachers, there were no clear trends for prediction accuracy (see Fig. 10). Some concepts posed more difficulty for some teachers more than others. For example, Teachers B and D's predication accuracy scores for *change in a population* were lower than Teacher A's. This result suggests Teachers B and D may potentially benefit from Teacher A's insight about how students think about this particular concept. The same could be said for Teacher C's insight towards *origin of variation* and Teacher D's insight towards *limited survival*.

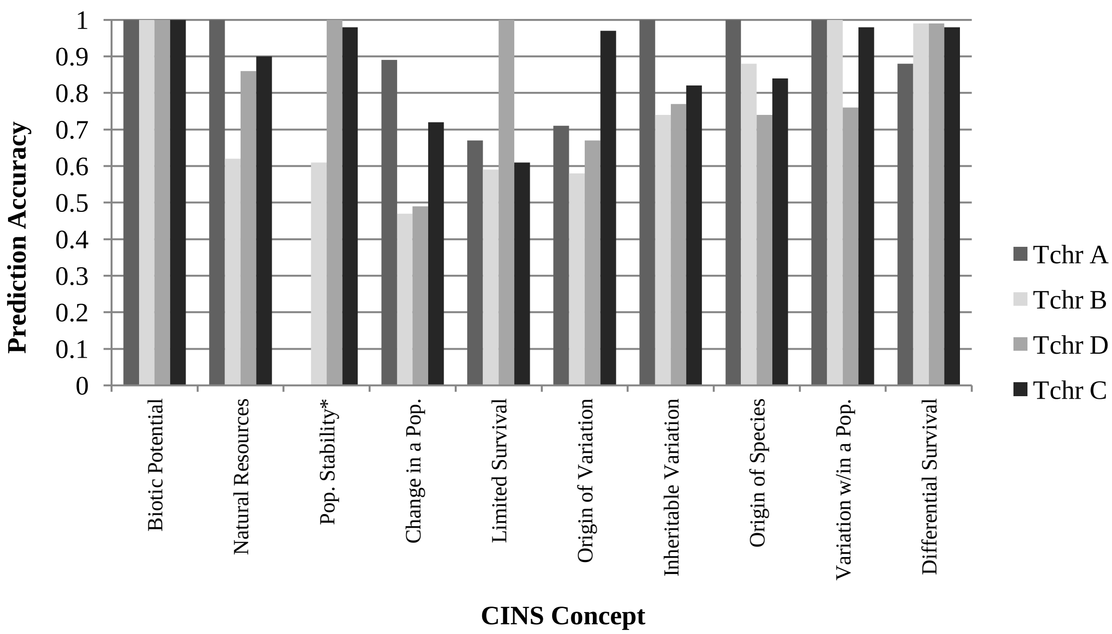


Figure 10: Teachers' average prediction accuracy of students' alternative conceptions on CINS concepts.
Note: * indicates no result due to Teacher A not making a prediction on both questions specific for *population stability.*

Elicitation of alternative conceptions during evolutionary instructional unit. As mentioned previously, all four teachers had their own distinct methods for eliciting their students' alternative conceptions. The common method was informal questioning, but there were also some other secondary forms (e.g., short written assessments, writing prompts) as well. The teachers' use of informal questioning to elicit alternative conceptions is discussed first.

Informal questioning as the primary means for elicitation. All four teachers had instances where they seemed to ask questions that were directly designed to elicit their students' alternative conceptions; however, when students would respond, there was a lack of teacher follow-up. Therefore, these questions may have been simply teacher attempts at engaging students in a discussion. An example from Day 1 of Teacher B's instructional unit illustrates this point:

> Teacher B: Today we are officially starting evolution. Does anybody know what evolution is? What's evolution?
> S1: It's like when monkeys turned into man.
> Teacher B: When monkeys turned into man...anything else?
> SS: Something about space...gorillas...dinosaurs...something that happened before our time...
> Teacher B: OK...Well, all those questions...all those conceptions that you guys have...all of those questions will be answered at around this time...(Class lesson, Day 1, 3/26/12)

There was no further probing of Teacher B's students during this interaction, and admittedly so by Teacher B:

> I didn't want to answer them. I just wanted to hear what they thought it was. I wanted to hear what their conceptions were. So I wasn't planning on answering any of them. I just wanted to hear what they thought. (Post-instruction interview, 4/25/12)

While Teacher B found the initial teacher-student interaction interesting, she did not necessarily use the information gathered from her students to inform the subsequent lessons in her unit.

Nevertheless, each teacher still asked questions that did elicit students' thoughts and ideas. One such example occurred on Day 3 of Teacher D's unit:

> Teacher D: So, frogs...what was an adaptation that they had?
> [Teacher D waits for students to answer.]
> Teacher D: What's an adaptation a frog has?
> S1: Tongues.
> Teacher D: Tongues? So, what would tongues do?
> S1: They could like catch a fly easily.
> Teacher D: Catch the flies...it helps them get their food easier, right? Maybe increase their chance...
> S1: And its color.
> Teacher D: Color...what about the color?
> S1: Like, if they're green, they could adapt to like a green environment.
> Teacher D: Right.
> S1: And if they're colorful, they could adapt to a colorful environment. (Class lesson, Day 3, 3/21/12)

This interaction between Teacher D and one of her students was different from the previously-described interaction with Teacher B in that Teacher D was asking a question designed to elicit alternative conceptions (i.e., if her students understood what an *adaptation* was), and wanted to hear more about what S1 had to say (as evidenced by follow-up questioning, "What would tongues do?" and "What about the color?"). If S1 had exhibited an alternative conception during this interaction, it may have encouraged further questioning by Teacher D and informed her subsequent planning.

However, interactions, like the one above with Teacher D and S1, were rare among every teacher's instructional unit. Every teacher had a certain amount of interactions dedicated to gauging their students' prior knowledge and alternative conceptions on a particular topic (see Table 19), but in almost every single case, there was a lack of follow-up in probing student thinking. Most interactions took the form of the following example from Teacher A:

> Teacher A: You behave one way at the mall or movies and a totally different way when you go to church...Is that an adaptation or is that an adjustment?
> S1: Adjustment.
> Teacher A: That's an adjustment. You are not physically any different...There's been no physical change, no behavioral change...An adaptation, in scientific terms, is an inherited characteristic that's passed on from one generation to the next that helps increase fitness...A lot of people are thinking very, very short-term. It's like one animal and it adapts to something...and that's its adaptation. That's not the case. It's born with it...You cannot acquire an adaptation. (Class lesson, Day 9, 4/2/12)

As can be seen from this interaction, Teacher A was ascertaining whether or not her students could distinguish an *adaptation* from an everyday *adjustment* and she followed a classic teacher-centered initiation-response-evaluation (I-R-E) discourse pattern. S1 answered correctly, but the answer came from a pre-determined 50% / 50% choice. Then, Teacher A proceeded to provide the explanation. In other words, even though this interaction was technically gauging an alternative conception, there was little room to further explore S1's ideas based on the way the question was asked.

TEACHER	**NO. OF TOTAL TEACHER-TO-STUDENT(S) INTERACTIONS IN INSTRUCTIONAL UNIT (ACADEMICALLY RELATED)**	**INTERACTIONS (%) CODED AS PROBING FOR ALTERNATIVE CONCEPTIONS AND PRIOR KNOWLEDGE**
TEACHER A	279	9%
TEACHER B	188	10%
TEACHER C	98	23%
TEACHER D	146	23%

Table 19: Amount of teacher-student(s) interactions probing for alternative conceptions and prior knowledge.

Overall, according to Table 19, there was a small amount of informal questioning dedicated to probing student alternative conceptions and prior knowledge within each teacher's practice, and less than 5% of these interactions actually indicated any teacher follow-up (e.g., "Explain what you mean by…") to student responses.

The teachers' use of informal questioning in this regard provided some insight into how it informed their practices. For Teachers B, C, D, students' prior knowledge was quickly leveraged and used to further adjust assignments. Since Teacher A believed her students had a poor science knowledge foundation, she relayed all pertinent information to her students. However, when she would occasionally ask her students' about their prior knowledge on a topic, she was pleasantly surprised when they revealed some substantial knowledge:

> Teacher A: 'Cause I don't think they pay much attention during class and I don't think that their science background is very good. So I don't know how much they would remember about fossils. I was...so surprised and happy when that other one said like, "'Cause of the...laying on the pressure on top and stuff." I'm like, "Yes! You remembered something there." And then the same thing with the tectonic plates...I wanted to bring that too 'cause some of them had mentioned it and they did remember that. So I thought maybe that would help tie it together...to help reinforce it...the idea. (Daily interview, Day 7, 3/29/12)

As a result of her informal questioning, Teacher A would then leverage student prior knowledge as well and further adjust her lessons. For all the teachers, the adjustments would come in the form of finding and using different representations (e.g., videos, pictures, diagrams, simulations) to further explain concepts. Also, overall knowledge about their students' tendencies (and not necessarily alternative conceptions) informed the sorts of assignments and instructional strategies that were employed during their instructional units. For example, since Teacher C knew his students had become technologically proficient with using different forms of software like Prezi and Animoto, he made sure to incorporate his students' technology skill set as part of his unit.

Writing prompts and short written assessments as secondary methods of elicitation. While Teacher A exclusively used informal questioning to gauge student knowledge, her three colleagues also employed other means of identifying alternative conceptions and prior knowledge. Teachers B, D, and C described using short writing prompts, assignments, and/or daily assessments. These three teachers employed written prompts at the onset of their instructional units to determine what their students knew about evolution. Teacher C structured his prompt differently, in that he placed it in the context of the video his students were about to watch:

> *Teacher C begins class by instructing students to take out their composition notebooks and turning to two empty pages. On one side they are to write "Evolution notes". On the opposite page they are to write "Evolution" at the very top and "How is this video related to evolution?" as the first heading. Below the heading, they are to number one through twenty, for they are to describe, in twenty different ways, how the upcoming video they will see is related to evolution.* (Class observation notes, Day 1, 3/28/12)
>
> S1: What's evolution?
> Teacher C: Like I said...I have not taught you guys anything. This is...merely my intro to it...I have not taught you guys anything about evolution, yet I am expecting you guys to tell me how the video I'm showing you guys is related to evolution. But I've never taught you guys anything about evolution...So this is basically what you guys already do know about it...(Class lesson, Day 1, 3/28/12)

Some of Teacher C's students had no familiarity with evolution whatsoever (see S1's question above) and this limited student awareness provided justification for Teacher C's writing prompt activity. Teacher C never described how his students' "20 ways" informed his subsequent planning.

Teacher C also relied on the use of his major assignments (i.e., word clouds, 30-second music videos) for information about how his students understood evolutionary concepts. However, Teacher C expressed dissatisfaction at the outcomes of these major assignments. The word clouds were meant to be examined by other students, but they never were. Moreover, Teacher C never described how these word clouds informed his practice. The students' lack of focus with their 30-second music videos prompted Teacher C to take an even more teacher-centered approach to the rest of his unit, as evidenced by his explanation to a student questioning why his class was taking notes:

> S1: Hey, what's this [note-taking] for?
> Teacher C: This?
> S1: Yeah.
> Teacher C: 'Cause you guys are...showing me most of your videos...and what I'm seeing from most of your videos is like a depiction of stuff that is changing, but I haven't really been seeing much biology...changes. And now I think it's...I feel like it's time for me to start addressing evolution that is strictly biology-based and that's what I'm going to start doing now. (Class lesson, Day 9, 4/10/12)

Teacher C felt his students were not making progress on learning accepted scientific conceptions. Therefore, he believed it was his responsibility to formally deliver this information.

Teacher B initially approached her students' thoughts on evolution with a verbal prompt and then, like Teacher C, proceeded to gauge her students' understanding by having them periodically answer (in their notebooks) open-ended questions within the context of the video they were about to watch:

> Teacher B: Alright...so I want you to think like Darwin would have. Why do you think...'cause those birds that he discovered...the finches that he discovered all came from a single species, but they were very different, especially when it came to their beaks...and then he looked at the tortoises and they too were different, especially from the different islands...why...think...you're Darwin and you just

came back from...and you're looking at your collection...why do you think there's those differences? Write that down...(Class lesson, Day 1, 3/26/12)

> Teacher B: So what do you think? Breeders have been doing it [artificial selection] already for years. They get these certain dogs and they select little traits to make other types of dogs. And so now, Darwin's asking himself, "If breeders can do this, is nature doing it too?" What do you think? Write that down. (Class lesson, Day 1, 3/26/12)

When prompted, Teacher B never described how her students' responses to these questions informed her subsequent lessons.

Besides informal questioning and written responses to the questions above, Teacher B also employed the use of short daily quizzes, especially towards the latter-half of her unit (Days 6-9), to gauge student understanding. These daily quizzes consisted of approximately five multiple-choice questions from released state assessments. Once students completed these quizzes, Teacher B always discussed the quizzes' questions and answers with her classes. Again, Teacher B never described how the students' results on these daily quizzes informed her teaching practice.

At the beginning for her instructional unit, Teacher D also used a writing-prompt to see what her students' thoughts were on the topic of evolution. Teacher D was more open-ended with her particular writing task:

> Teacher D: OK. So, what we're going to do today is we're going to start our topic on evolution. So, what I want you to do before we even start is I want you...I'll give you a sheet of paper and you're going to write down your thoughts on evolution. What does it mean to you? What comes to mind? it doesn't have to be complete thoughts. It's just whatever comes to mind when you think of evolution...I want you to write it down. (Class lesson, Day 1, 3/19/12)

The students' responses to this prompt were informative to Teacher D, in that they provided some insight and confirmed how she should approach the beginning of her instructional unit:

> Teacher D: Um...well, some of them might be a little off...but I was happy to hear that "change" was the common word...so that's important to know that...yeah...it's change...so, that kind of gave me a way to lead into it, I guess, with evolution...things change, but then go into more specifically,...the exact definition of it. So, while their...maybe it was slightly off...they were kind of...seem to...the ones that did voice it...were on the right kind of path, I guess. (Post-instruction interview, 4/23/12)

Knowing that her students could identify with the concept of “change”, Teacher D realized at this point that her students’ ideas were something with which she could work.

Teacher D routinely began every class of her instructional unit with a daily assessment, or “Mission Countdown” (as she called it). Each assessment took the form of a daily quiz which usually had 3-5 questions. Some questions were multiple-choice in style and others had a short answer format. Like Teacher B, Teacher D always discussed the questions and answers of these Mission Countdowns with her students once they completed them. Teacher D was the only teacher who mentioned how information from daily assessments informed her practice. Here is one such example:

> Teacher D: Well...I guess just from the last class, I looked at the Mission...I gave them back their Mission Countdowns and then I did see that...with some of the definitions that they were getting natural selection kind of wrong...the idea was kind of off. So I…I kind of wanted to emphasize again what that was...what natural selection was. (Daily interview, Day 4, 3/23/12)

Teacher D viewed her Mission Countdowns as providing insight into which concepts were posing difficulty to her students. If Teacher D noticed many of her students were having trouble with a concept, especially after answering a daily assessment, then she would quickly make attempts to re-adjust her lesson. If she could not make adjustments that same day, then she tried to do so the following class meeting. Most often, these adjustments took the form of Teacher D spending extra time with a concept, usually by asking more questions and/or providing more examples and representations.

Summary. In addition to being assessed with the CINS themselves, the teachers in the current study used the CINS to predict their students' most common alternative conceptions. In order to see how aware the teachers were of their students' ideas/areas of difficulty, it became necessary to develop a method to measure the accuracy of the teachers' predictions on the CINS. The measure revealed that the teachers were relatively accurate with their predictions. This finding indicates the teachers had an overall awareness of the types of alternative conceptions they were likely to find with their students.

However, even though the teachers possessed an awareness of their students' natural selection alternative conceptions, it was not routinely prioritized when the teachers planned for their lessons. The teachers did not often set out to gauge students' thoughts before a concept was formally introduced or became the focus of a lesson. Besides the implementation of the CINS as a pre-/post-test, the teachers also employed informal questioning, short daily assessments, and occasional writing prompts as other forms of gauging student knowledge. Many of these forms served as review for the students, but they may have also provided insight into whether or not the students were altering their alternative conceptions. All the teachers placed value on student knowledge and how it could enhance the quality of a lesson, but they also acknowledged that it took time to probe students' thoughts on a deeper conceptual level. This may explain why the teachers rarely engaged in discourse that involved follow-up questioning of specific alternative conceptions.

Research Question #3: Does the teachers' *subject matter knowledge (SMK),* with respect to natural selection, relate to the knowledge of their students' alternative conceptions? How does the teachers' SMK manifest itself when students reveal their natural selection alternative conceptions during classroom instruction?

Within the topic of evolution, if student alternative conceptions are unfamiliar among teachers and not recognized among students, it may be difficult for students to use these conceptions as resources for learning new concepts. One of the main reasons as to why this may occur is a lack of domain-specific PCK among biology teachers, which may fail to develop because of inexperience in the profession and/or content area (Gess-Newsome & Lederman, 1993). While this study does not seek to measure or describe a teacher's entire knowledge base where evolution is concerned, it is an initial step in gauging and describing two of its components—SMK and PCK's knowledge of areas of student difficulty (students' ideas). While it is interesting to observe which alternative conceptions the teachers themselves may or may not possess, it is particularly insightful to see *how* this knowledge relates to their ability to predict which alternative conceptions their students may have and is manifested when their students' alternative conceptions become apparent during instruction.

Teachers' content knowledge on CINS. As mentioned previously, each teacher predicted his/her students' most common alternative conceptions on the CINS, while being assessed with the CINS themselves. Each teacher's results are summarized in Table 20.

QUESTION	CINS CONCEPT	TEACHER A		TEACHER B		TEACHER D		TEACHER C	
		Missed Question?	Prediction Accuracy	Missed Question?	Prediction Accuracy	Missed Question?	Prediction Accuracy	Missed Question?	Prediction Accuracy
#1	BIOTIC POTENTIAL	YES	1.0	YES	1.0	YES	1.0	NO	1.0
#11	BIOTIC POTENTIAL	NO	1.0	NO	1.0	NO	1.0	NO	no prediction
#2	NATURAL RESOURCES	NO	1.0	NO	.24	YES	.71	NO	.80
#14	NATURAL RESOURCES	NO	1.0	NO	1.0	NO	1.0	NO	1.0
#3	POP. STABILITY	NO	no prediction	NO	no prediction	NO	1.0	NO	.95
#12	POP. STABILITY	NO	no prediction	YES	.61	YES	1.0	YES	1.0
#4	CHANGE IN A POP.	YES	.77	YES	.43	NO	.61	YES	.54
#13	CHANGE IN A POP.	YES	1.0	NO	.50	NO	.36	YES	.90
#5	LIMITED SURVIVAL	NO	.33	NO	.24	NO	1.0	NO	.22
#15	LIMITED SURVIVAL	NO	1.0	NO	.93	YES	1.0	NO	1.0
#6	ORIGIN OF VARIATION	YES	.66	NO	.61	NO	.43	NO	.93
#19	ORIGIN OF VARIATION	NO	.76	NO	.55	NO	.90	NO	1.0
#7	INHERITABLE VARIATION	NO	1.0	NO	.53	NO	1.0	YES	.86
#17	INHERITABLE VARIATION	NO	1.0	NO	.95	NO	.53	YES	.78
#8	ORIGIN OF SPECIES	NO	1.0	NO	.88	NO	.59	YES	.67
#20	ORIGIN OF SPECIES	YES	1.0	NO	.87	NO	.88	NO	1.0
#9	VARIATION W/IN A POP.	NO	1.0	YES	1.0	NO	.78	NO	1.0
#16	VARIATION W/IN A POP.	NO	no prediction	NO	no prediction	NO	.73	NO	.95
#10	DIFFERENTIAL SURVIVAL	NO	1.0	YES	1.0	NO	1.0	NO	.96
#18	DIFFERENTIAL SURVIVAL	NO	.76	NO	.97	NO	.97	YES	1.0

Table 20: Teacher performance and prediction accuracy (optimal score is 1.0) of student alternative conceptions on CINS. Shaded cells indicate incorrectly answered questions.

Table 21 lists each teacher's prediction accuracy results when considering only those questions which the teachers, themselves, answered correctly. Table 22 summarizes the prediction accuracy results when only incorrectly answered questions are considered. A one-way ANOVA revealed there was no statistical significance among the teachers' prediction accuracy scores in both contexts.

TEACHER	NO. OF CORRECT QUESTIONS (N=20) ANSWERED ON CINS	TOTAL PREDICTION ACCURACY (CORRECT QUESTIONS)
TEACHER A	12	0.90 (SD=.20)
TEACHER B	13	0.71 (SD=.28)
TEACHER C	11	0.90 (SD=.23)
TEACHER D	16	0.80 (SD=.22)

Table 21: Teachers' prediction accuracies of their student alternative conceptions on the CINS for number of questions answered **correctly** by teachers.

TEACHER	NO. OF INCORRECT QUESTIONS (N=20) ANSWERED ON CINS	TOTAL PREDICTION ACCURACY (INCORRECT QUESTIONS)
TEACHER A	5	0.89 (SD=.16)
TEACHER B	5	0.81 (SD=.27)
TEACHER C	8	0.84 (SD=.16)
TEACHER D	4	0.93 (SD=.15)

Table 22: Teachers' prediction accuracies of their student alternative conceptions on the CINS for number of questions answered **incorrectly** by teachers.

Table 21 indicates that when considering the number of correctly answered questions for each teacher's accuracy measure, a closer examination of the data is necessary. If examining just the teachers' correctly answered CINS questions exclusively, Teachers A, B, and C had between 11 and 12 questions used in the prediction accuracy measure. Most of this was due to a certain number of incorrectly answered questions not being counted towards the prediction accuracy measure for each teacher, but another reason was because some teachers simply could not predict a potential alternative conception for their students. In other words, the teachers believed the majority of their students would "have no problem" with a particular question in several cases. While this sort of reasoning may be acceptable, believing students will have little or no difficulty with a concept seems to indicate a lack of knowledge for student ideas within certain domains of evolutionary thinking. Teacher C had the most number of questions (n=8) not counted towards this particular measure due to his own alternative conceptions and one question was not counted because of a non-prediction. Teachers A and B had a balance of questions that demonstrated personal alternative conceptions (n=5 and n=5, respectively) and questions with non-predictions (n=3 and n=2, respectively). Teacher D, the novice, might actually have the most reliable score (0.80) in this regard because almost all of her questions were used in the calculation of this particular measure.

When examining the predictions according to each correctly answered question and concept, there were no clear trends (see Figure 11). In fact, only three questions (#14, #5, and #19) had prediction accuracy measures for all four teachers. All other questions had three or less teachers associated with prediction accuracy. Of the three questions with measures from all four teachers, there was only one question (#14) that demonstrated consistency with the teachers' predictions. Question #14 assessed thinking on *natural resources*. All four teachers, as can be seen from Figure 11, had a prediction accuracy score of 1.0 on this question, which indicated a strong confidence in familiarity with their students' alternative conceptions for this particular question, but not necessarily concept because the results for Question #2 (which also assessed *natural resources*) revealed more inconsistency, especially considering the results for Teacher D were not counted toward the measure.

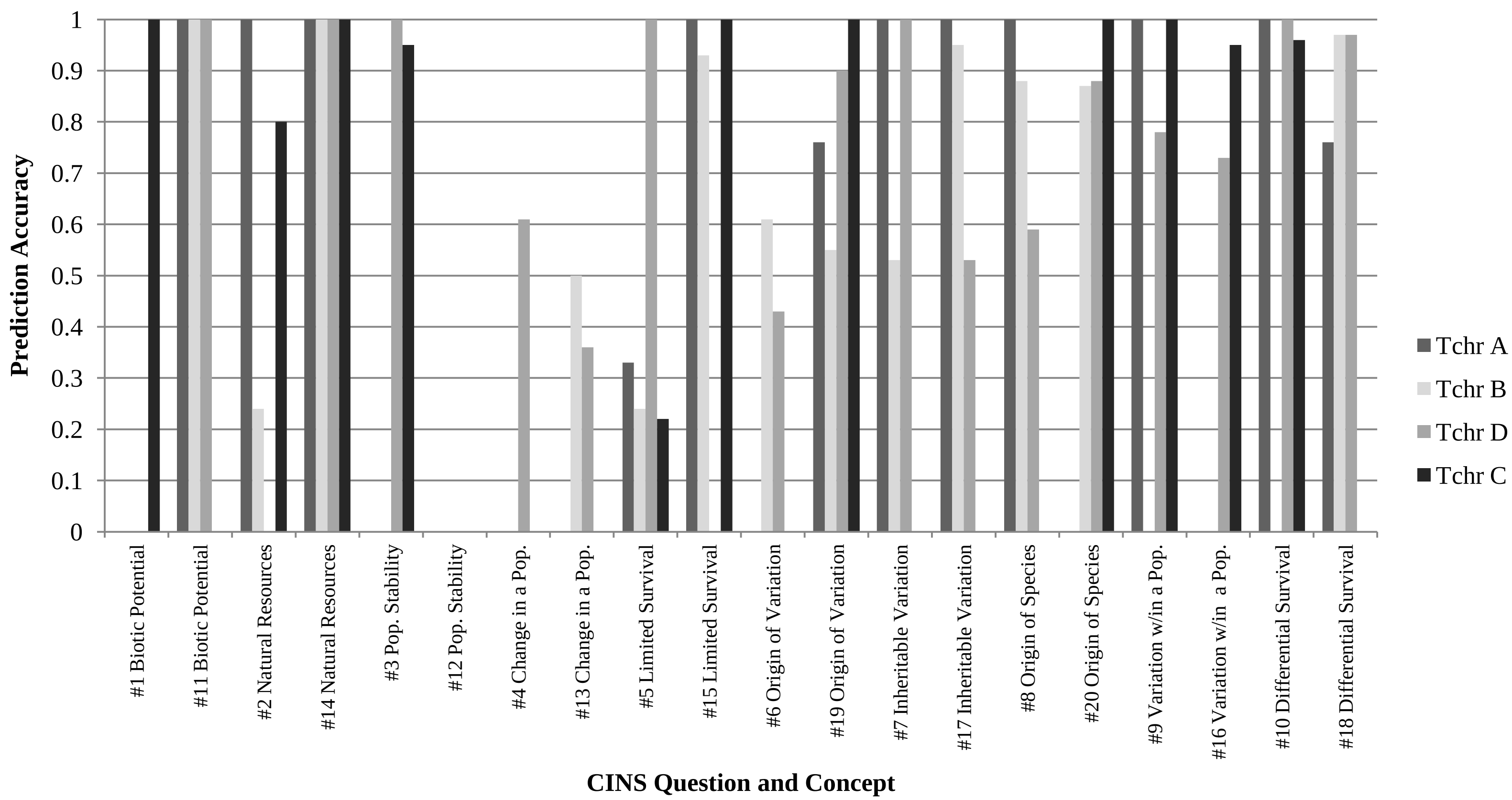


Figure 11: Teachers' prediction accuracy of students' alternative conceptions according to **correctly** answered CINS questions and concepts.

Overall, these prediction accuracy results confirmed the lack of discourse about student thinking among this group of teachers. Even among the three teachers (Teachers A, B, and D) who made attempts at common planning, only eight correctly-answered CINS questions (#5, #7, #8, #11, #14, #17, #18, #19) had prediction accuracy measures common to all three teachers and some of these measures had varying results. While it is not expected that this group of teachers should think as a unit exclusively, it became apparent that these teachers, at least, needed to be afforded opportunities to discuss possibilities for their students' alternative conceptions.

As can be seen from Tables 21 and 22, every teacher was still able to predict, with relative accuracy, his/her students' natural selection alternative conceptions—even on the questions they themselves missed. This result suggests the teachers' SMK (as measured by the CINS) is independent of their knowledge for their students' ideas/areas of difficulty. Table 23 also relays information about which CINS concepts each teacher had difficulty with and shows the number of teachers correctly answering specific CINS questions (and associated concepts).

#1 Biotic Potential C	#11 Biotic Potential A, B, C, D	#2 Natural Resources A, B, C	#14 Natural Resources A, B, C, D
#3 Pop. Stability A, B, C, D	#12 Pop. Stability A	#4 Change in a Population D	#13 Change in a Population B, D
#5 Limited Survival A, B, C, D	#15 Limited Survival A, B, C	#6 Origin of Variation B, D	#19 Origin of Variation A, B, C, D
#7 Inheritable Variation A, B, D	#17 Inheritable Variation A, B, D	#8 Origin of Species A, B, D	#20 Origin of Species B, C, D

4 teachers
3 teachers
2 teachers
1 teacher

#9 Variation w/in a Pop. A, C, D	#16 Variation w/in a Pop. A, B, C, D	#10 Differential Survival A, C, D	#18 Differential Survival A, B, D

Table 23: CINS questions (by concept) answered correctly by individual teachers (A, B, C, D). Note: Different cell color indicates number of teachers with correct responses on CINS questions.

When considering the teachers as a group, certain CINS concepts posed more conceptual difficulty than others. For example, *natural resources, limited survival,* and *variation within a population* were three CINS concepts that almost every teacher answered correctly (see Table 23); whereas *change in a population* had the least amount of correct responses. However, out of the entire CINS, only six questions were answered correctly by **all four teachers**. Even when one considered the three teachers who participated in common planning (Teachers A, B, and D), the results were very inconsistent across concepts and questions, signaling the differences with which these teachers think about the CINS concepts.

Manifestation of teacher SMK with managing student alternative conceptions. In order to determine how each teacher's SMK affected his/her management of student alternative conceptions, it was necessary to examine how he/she handled the alternative conceptions once they became apparent in real classroom-time. The results for the research question #2 dealt with how each teacher identified student alternative conceptions and if this knowledge informed each teacher's practice. The present research question now addresses how these teachers' SMK dealt with the student questions, comments, and responses that were revealed to be alternative conceptions on the topic of evolution. Video analysis determined certain themes became evident when the teachers encountered alternative conceptions. While not every teacher demonstrated each and every theme, the themes were common among this group of teachers. The themes are listed and described below.

Rephrasing of student alternative conceptions. In some instances when a student alternative conception was made known, the teachers (or other students) rephrased the student idea to make it more clear and understandable. In the following example, Teacher D and her students were discussing common ancestry, but some student questions remained:

> S1: So then we're related to...we came from plants too?
> Teacher D: It's not that we came from plants.
> S1: So we were once plants?
> SS: Oh my God...No...Plants don't have arms!
> Teacher D: It's saying that we all have a common ancestor.
> S1: Well, it's because that's what she [Teacher D] said!
> [Various student chatter ensues.]
> Teacher D: We're all related to a common ancestor. Millions and millions of years back, they're saying living things came from like the ocean…(Class lesson, Day 6, 3/29/12)

S1's alternative interpretation of human common ancestry to include the evolution from plants allowed for an emphatic rebuke from other students and Teacher D's re-wording of common ancestry. Towards the end of this interaction, Teacher D was beginning to refer to ancient marine life forms to make the concept of common ancestry a bit less abstract.

The next example has other students rephrasing a student idea. In this instance, Teacher C was asking a follow-up question of a student who just presented her 30-second music video:

> S1: By like how doctors back then...they didn't have that much medicine and what they did...like they helped us, but now...now that we have the medicine that we need, we're just abusing like...
> Teacher C: And how does that affect...
> S2: It kills us.

> Teacher C: How does that affect evolution?
> S3: The environment...
> S4: It's making us stupider...
> S1: Like our generation...we're dumber than...to be smarter? I don't know...
> S5: No...I think what she's trying to say is all the chemicals that you put in your body is getting your DNA weakened, so your next generation or your kids are gonna come out a little bit abnormal than what you think they should be...from using the drugs.
> Teacher C: So then you're saying taking something...that's supposed to be beneficial and abusing it, eventually you're gonna...you're saying there's going to be causes on it. (Class lesson, Day 7, 4/9/12)

In this interaction, S5 was attempting to synthesize his fellow students' comments into what S1 was trying to articulate. Teacher C then intervened and attempted to rephrase the students' still-alternative idea that DNA mutations (once acquired from medication abuse) are passed down to immediate generations. Teacher C acknowledged S1's idea, even though the students might still have been left with the overall alternative conception that evolutionary change can occur quite quickly within one generation and acquired traits (including a DNA mutation from taking medication) in a lifetime can be inherited.

Overall, Teachers D and C's interactions demonstrated a disparity in how these two sorts of student alternative conceptions were managed. Granted, the two alternative conceptions did not involve the same exact idea, but a difference can be seen in how each was handled. Both interactions involved other students intervening, but Teacher D began to bring the concept of common ancestry back to something to which Teacher D knew her students could relate (marine life). Teacher C allowed his students' ideas to continue, but ran unchecked until the very last moment. These interactions suggest that Teacher D's SMK is being leveraged somewhat in knowing how to guide her students' ideas.

Addressing student alternative conceptions with factual information and data. All four teachers would commonly address their students' alternative conceptions with factual information and data. With interactions such as these, a teacher would acknowledge a student alternative conception and then respond with factual information that was already personally known or through a referral to the student textbook and then proceed to another topic. These interactions were typically short in duration and did not include teacher follow-up questions of why or how students were thinking the way they were. Here is an example from Teacher D's class where mutations were being discussed:

> S1: So you say that everything started off as a little...bacteria, right?
> Teacher D: Everything came from a common ancestor.
> S1: Yeah...so how did we decide to change?
> Teacher D: There was mutations that occurred throughout the way and then it led to different types of species...because of these mutations. But it's gradual. It takes a long time for that to happen. (Class lesson, Day 1, 3/20/12)

In this interaction S1 believed organisms had a decisive role in determining evolutionary paths. Teacher D answered S1 with a matter-of-fact approach by explaining how mutations introduce variations in a population. Teacher D did not explore S1's thinking any further, by possibly asking S1 what he meant by "decide to change."

Immediate leveraging of student prior knowledge. There were instances where a teacher managed an alternative conception by drawing on students' prior knowledge. The prior knowledge was not necessarily specific to a deep conceptual understanding of a scientific concept, but mostly on general, surface-level, popular knowledge. Here is one such example from Teacher B's class:

> S1: If we evolved from fish, why aren't people evolving to *(inaudible)*...like why aren't we evolving into different things now?
> Teacher B: Are we not?
> S1: Yeah...like why aren't we right now?
> Teacher B: Are we not?
> SS: No...We are...
> Teacher B: When were the first humans found?
> *Various student chatter...*
> Teacher B: Millions of years, right? The first humanoids were millions of years before. So is it possible that we're still evolving? (Class lesson, Day 1, 3/26/12)

In this particular example, S1 held the alternative conception that evolution occurs within a relatively short time frame—that one should be able to see a transformation. Teacher B took notice of this alternative conception and leveraged the students' possible prior knowledge about fossils and the age of the human fossils, in particular, with her follow-up question of "When were the first humans found?" Upon hearing how long humans have been on Earth, S1 and other students may have realized that evolution is a gradual process and they were not likely to witness transformative changes in the human species during their lifetimes.

Selective listening for correct answers. As mentioned previously with RQ#2's findings, informal teacher questioning was the primary means of identifying student alternative conceptions. When the student responses were revealed to be alternative conceptions, not all were acknowledged by teacher, and may have been entirely overlooked in some cases. This oversight usually took the form of teachers either repeating the same initial question or waiting to respond until a correct answer was expressed. In these cases, the teachers explained they would have been quite eager to explore their students' thoughts and ideas, but their time schedule and curricular demands simply did not warrant the extra time spent with student thinking. The following example was representative of this type of interaction:

> Teacher A: What kind of environment do you think this little Isabella Island tortoise lived in?
> S1: Dirt.
> S2: Rocks.
> S3: The ocean.
> Teacher A: Where do you think it's gonna find its food?
> SS: In the ocean...on rocks...on the ground.
> Teacher A: On the ground...Why on the ground?
> S4: 'Cause it's small...low.

> Teacher A: 'Cause it's small...It's got a really tiny head and neck, right? (Class lesson, Day 1, 3/20/12)

In this interaction from Teacher A's class, three different students named three different places where the tortoise could possibly live. Teacher A did not follow up with asking why each student thought the way he/she did. Instead, Teacher A then rephrased the question a bit and did not respond again until the correct answer was heard ("the ground" in this case). It was at this point that Teacher A asked a follow-up question from hearing the correct response.

Summary. Based on the teachers' performance and prediction accuracy on the CINS, it appears that these teachers separated their own personal knowledge of natural selection from that of their students' when asked to reflect on their students' knowledge on the topic. However, when their students' revealed their personal alternative conceptions during classroom instruction, the teachers' different knowledge of evolutionary concepts became more apparent in the manner with which the alternative conceptions were handled. The above examples that described how Teacher D and Teacher C handled student-student discourse demonstrated these SMK differences. Nevertheless, Teacher A, Teacher B, and Teacher D, with their consistent focus on right answers, positioned themselves as the knowledge authorities in their classrooms. In contrast and interestingly, Teacher C's uneasiness with evolutionary concepts enabled him to approach the topic from a more student-centered perspective, even though many of his students' alternative conceptions remained the same post-instruction (student outcomes on CINS are summarized in RQ#5's results).

Research Question #4: How do teachers view the concept inventory's utility as a classroom tool for gauging student understanding of natural selection?

As mentioned previously, each teacher's students were assessed with a modified version of the CINS both before and after each teacher's respective instructional unit on evolution. After each teacher's students were assessed, the students' results were compiled and distributed to each teacher. Each teacher received an overall breakdown of his/her students' results according to each question on the CINS (see example shown in Figure 8 in Chapter 5). The teachers' classroom use of the CINS is described from its introduction as a pre-test. While the teachers' views on the CINS's classroom utility were emergent themes from the different interviews, it was still necessary to track each teacher's common planning meeting and classroom events to gauge how (or if) the students' pre-test performance on each of the CINS concepts influenced the teachers' practices. The prevalence of these concepts during each teacher's classroom observations is also reported through the use of their teacher-student interactions and instructional activities. Finally, with the exception of Teacher D, each teacher provided suggestions as to how the CINS could be further adapted for classroom use and a discussion of these suggestions is also presented within each teacher's results.

Administration of the CINS. Even though the teachers were introduced to the CINS as part of their individual assessments, the CINS's first classroom use was as a pre-test administration given to their students. Each teacher spent one day administering the CINS and described his/her impressions from the administration.

Student frustration with reading passages and overall length. According to Teachers A, B, and D, their students expressed grumblings about the amount of reading that was involved with answering each set of questions. Teacher A said her students thought the CINS's reading passages were too long. In addition, her students expressed extreme frustration and dislike at being assessed with the CINS before the instructional unit began. Her students were quite apprehensive at being assessed with a pre-test, but Teacher A tried to allay their fears about not being that familiar with evolutionary concepts. Teacher A remained somewhat skeptical of her students' pre- and post-test results because of her concern that some of her students may have resorted to guessing on questions due to the CINS's length. According to Teacher A:

> The hardest part was trying to make good valuable use out of it because the kids hated it. It was too long for them...But, like once they got through they were like, "Oh my gosh. There's still so much more to go." They completely lost interest and they were distracted. They don't like to read. They hate reading (Post-instruction interview, 4/25/12).

Teacher A believed her students' pre- and post-test results would have had more value and utility had her students maintained their concentration with one reading passage at a time.

According to Teacher C, his students may have voiced the normal negative sentiments when encountering the CINS, but once they were "in the throes" of the CINS, many students maintained an attentive focus to the CINS and tried to answer the questions to the best of their abilities.

Value of CINS's conceptual approach to assessment. The teachers had no familiarity with the CINS before the current study began. They all were used to other forms of formal written assessment, such as district-written benchmark tests and textbook-written daily warm-up questions and unit tests. As novices with the CINS, it was important to gather their overall impressions of the CINS as a form of assessment.

Provides useful information about student thinking—either confirmation or revelation. After reviewing her students' pre-test results, Teacher A commented that the results confirmed what she already knew about her students' alternative conceptions. Nevertheless, she did appreciate the breakdown of her students' data and some of the results helped her with realizing and confirming which evolutionary concepts needed to be stressed throughout her instructional unit. For example, Teacher A described how the concept of *biological fitness* (or *differential survival,* in CINS terminology) was particularly important: "It's like...with the fitness and what does that mean to them and stuff...so that was like, 'Uh-huh...kind of figured'...mostly in that way. It's like…those are the particular areas that we need to hit (Post-instruction interview, 4/25/12).

Teacher B welcomed the CINS as a form of assessment and found it to be more useful in relaying student understanding as opposed to other forms of assessment, such as results from the state-mandated tests:

> I think what I like about it is you get the preconceived notions other than what they normally give you…It's more focused on particular topics...certain questions...they may be questions on any test. I think this is more informative than this [samples of state assessment questions]...And the data to me is more valuable than this [referring again to state assessment questions]. So I like this. I'm actually considering adopting something like this later. (Post-instruction interview, 4/25/12)

She also found value with the student results that were presented to her after the pre-test administration. Teacher B admitted pleasant surprise with the way her students answered some of the questions and used some of the results as an additional guide for planning instructional activities and deciding which concepts really needed to be stressed and those that did not:

> What I did like about it...is it gave me an idea of what they understood and what I didn't know that they understood. And I kind of like that because there some stuff

> that I chose that they didn't, and I was like, "Oh wow...They do understand this a little more than I thought they had." So that was kind of nice. It kind of helps you with the lesson in the sense that I'm like, "Well, I don't really have to go and talk about that because they do know." So I can kind of just skim through this. (Post-instruction interview, 4/25/12)

However, Teacher B expressed concern for how many different concepts were included within the CINS. She believed that if the CINS concepts had been more closely tied to the school district's curricular scope and sequence, then she may have been able to utilize it more as a classroom tool.

The novice of the group, Teacher D found herself still being acquainted with the various forms of assessment made available to her. She explored her different options and found the CINS to be a useful form of assessment in that it provided practical information about how her students understood natural selection concepts, especially with *differential survival*. From this information, Teacher D occasionally tweaked her instructional unit in different places to ensure her students received optimal engagement with natural selection concepts. Teacher D cited an example:

> …'Cause when I looked at that, I could see what they would be thinking for fitness. So, I did give more like examples of what fitness...well, which one do you think is more fit and then we would do that. I had a mission countdown, I think, too. So, I added that. (Post-instruction interview, 4/23/12)

Overall, Teacher D had less to say about how she used the CINS in comparison to her colleagues. While her fellow biology teachers, Teachers A and B, thought the CINS probed students more deeply than other traditional forms of assessment, Teacher D never discussed the CINS in relation to other assessments and remained rather impartial to the CINS. However, as a teacher who believed her students brought significant prior knowledge about evolution to the classroom, she felt her students' pre-test results contributed insight to what she believed her students already knew about natural selection concepts. According to Teacher D, the results seemed to confirm the approach she was ready to take when embarking on her instructional unit:

> …Your test actually helped…first seeing what they already know about evolution…seeing…do they know what evolution is and then kind of start talking about the history…so, like Charles Darwin and how he came about…to start studying evolution. (Pre-instruction interview, 3/9/12)

Like his colleagues, Teachers A and B, Teacher C also appreciated the manner in which the CINS probed conceptual understanding. For Teacher C, this view was somewhat of a departure from his initial impressions of the CINS. When first exposed to the CINS, Teacher C believed his students were going to have extreme difficulty with and voice resistance to such an assessment because of the students' lack of familiarity with the Galapagos finches, Venezuelan guppies, and Canary Island lizards found in the CINS reading passages. Teacher C said, "…I think the hardest part…with all these questions already is you have to be in the mentality of an animal. You have to already be thinking about…survival and what it means to survive in the wild. And I think a lot of kids have not even gone out camping" (Pre-instruction interview, 2/28/12).

Once his instructional unit had concluded and upon further examination of the CINS, Teacher C began to see potential value with the CINS and the type of information it could convey:

> That's what I liked about it. It's a lot of switching up with the words...a lot of play with the words. I thought that was something good. If it was a question where it was something similar to this, I would prefer...versus something where it's like...well you've seen like the [state assessment] test. (Post-instruction interview, 4/27/12)

Teacher C communicated a realization that the state assessment and the CINS are vastly different in their approaches at probing conceptual understanding. Whereas procedural learning and rote memorization seem to be valued with state assessments, Teacher C was intrigued by the notion of the CINS's format. The CINS's closely related answer choices would give students a challenge, but their responses would relay valuable information about how the students were thinking about such concepts:

> Even I had to stop and think seriously about this. And what I remember watching my students, I saw them spending a lot more time on that...It looked like they were concentrating more...The reason why they're concentrating more is 'cause it [the CINS] was different. It was very similar statements and I think that's what they struggled with. (Post-instruction interview, 4/27/12)

Teacher C stated that he did use the students' pre-test results to help guide his instruction and planning, but justification of his claim is difficult to ascertain as there exists little evidence. He provided no specific examples as to how the CINS results were affecting his practice. He mentioned he paid particular attention to the CINS concepts his students found difficult and made an effort to incorporate and concentrate on these concepts more than he normally would. However, evidence pertaining to his claim was elusive because of the few total interactions that exist with his students regarding these concepts. In addition, there was a lack of instructional activities in which his students were engaged with these concepts (see next section).

Prevalence of CINS concepts throughout instructional unit. As mentioned previously, ten concepts encompass natural selection on the CINS. Figure 12 displays how often each CINS concept occurred over each teacher's instructional unit. Overall results yielded a significant one-way ANOVA on the means for each CINS concept's occurrence, $F(9,30) = 3.49$, $p < .005$. Post-hoc testing using Tukey's Honestly Significant Difference (HSD) Test revealed that the CINS concepts of *inheritable variation* and *differential survival* were significant at the .05 level for being emphasized more so than other CINS concepts during the teachers' instructional units.

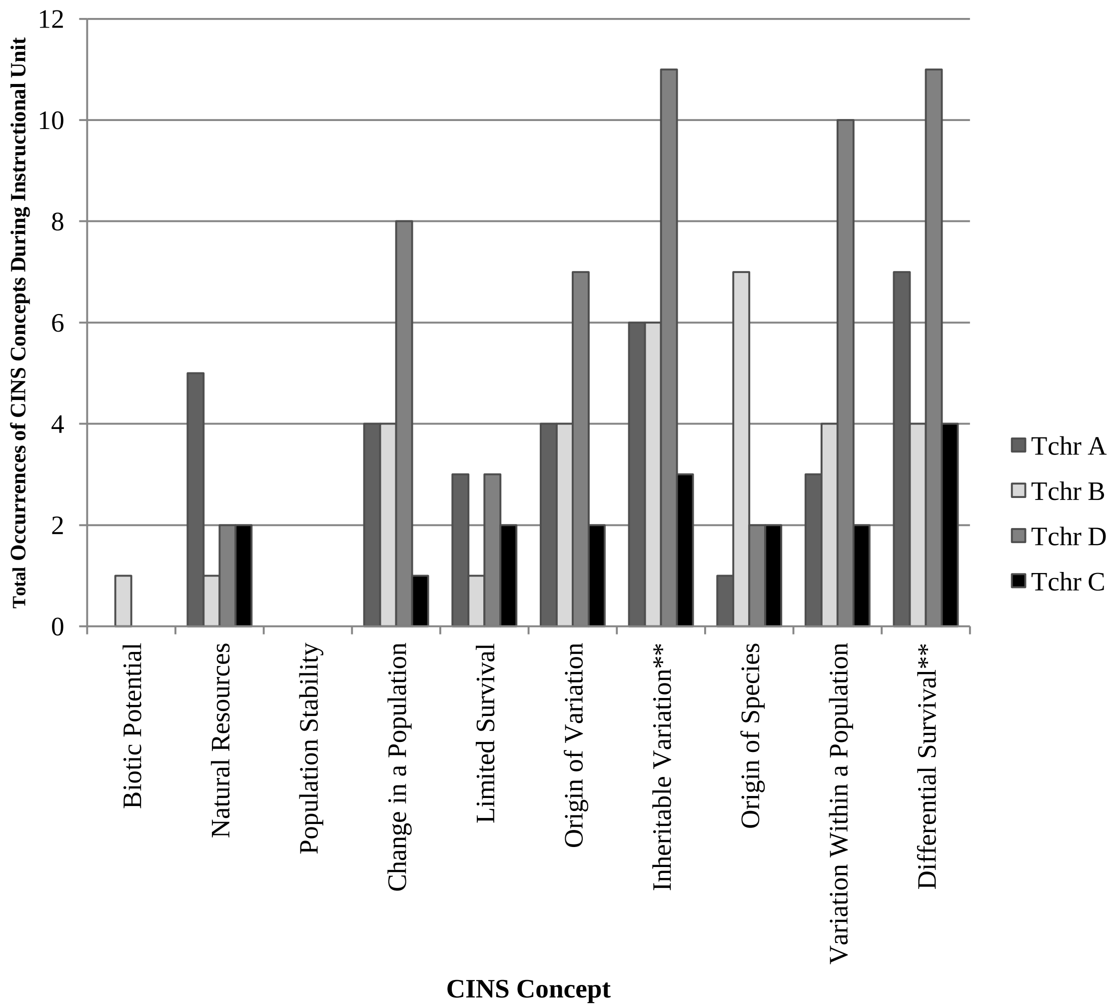
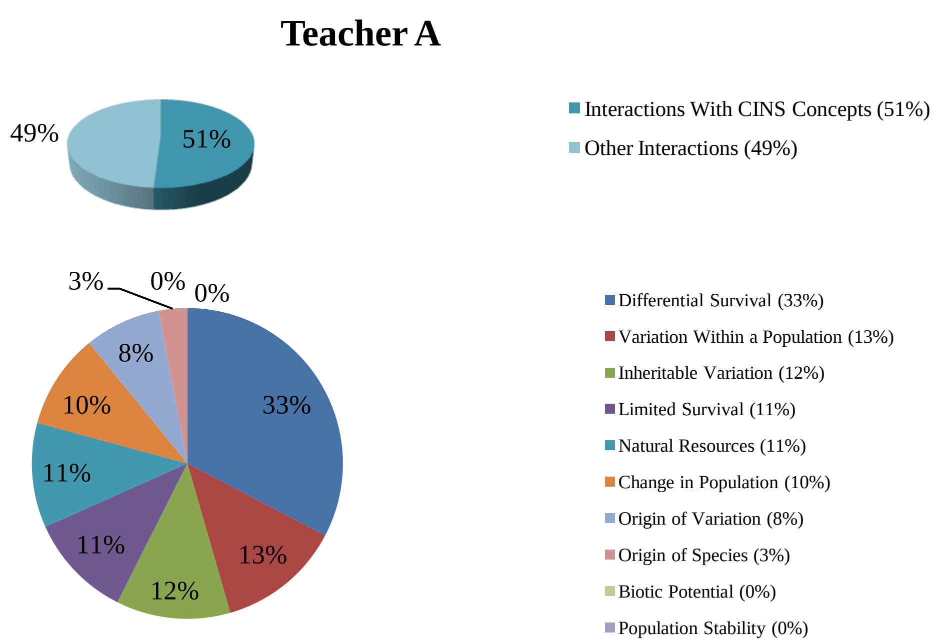
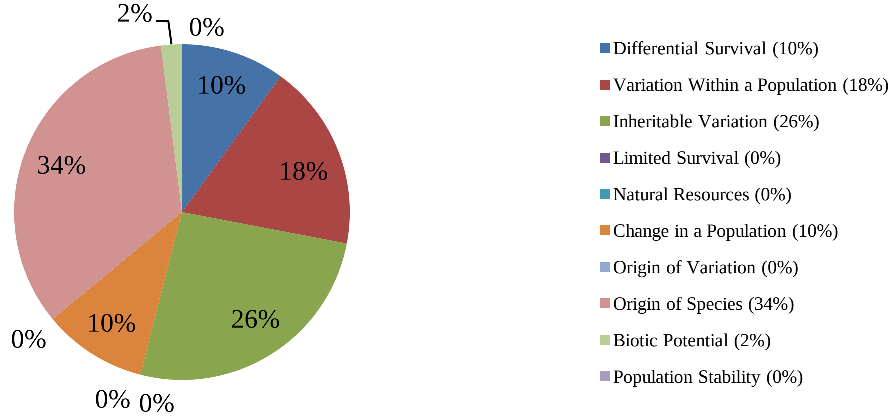


Figure 12: Total number of targeted CINS concepts found within instructional activities across each teacher's evolutionary unit.
** occurrences during instructional unit significant at $p < .05$

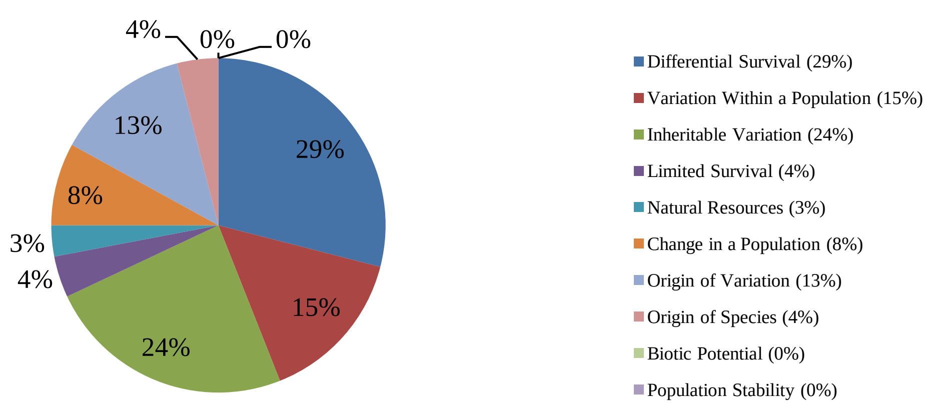
Teacher A had her students engage with almost all (with the exception of two, *biotic potential* and *population stability*; see Figure 13) of the CINS concepts in some form or another during her instructional unit. An avid questioner of her students, Teacher A had an approximate 181 interactions with her students throughout her instructional unit and of those interactions, approximately 51% (n=92) were devoted to CINS concepts. Several of her instructional activities also coincided with various CINS concepts (see Figure 12) and some of these concepts appeared more frequently (e.g., *differential survival*, *inheritable variation*) than others with the selection of these activities. Not surprisingly, the frequency of these concepts with her instructional activities matched the frequency of her interactions with her students.



Teacher B



Teacher D



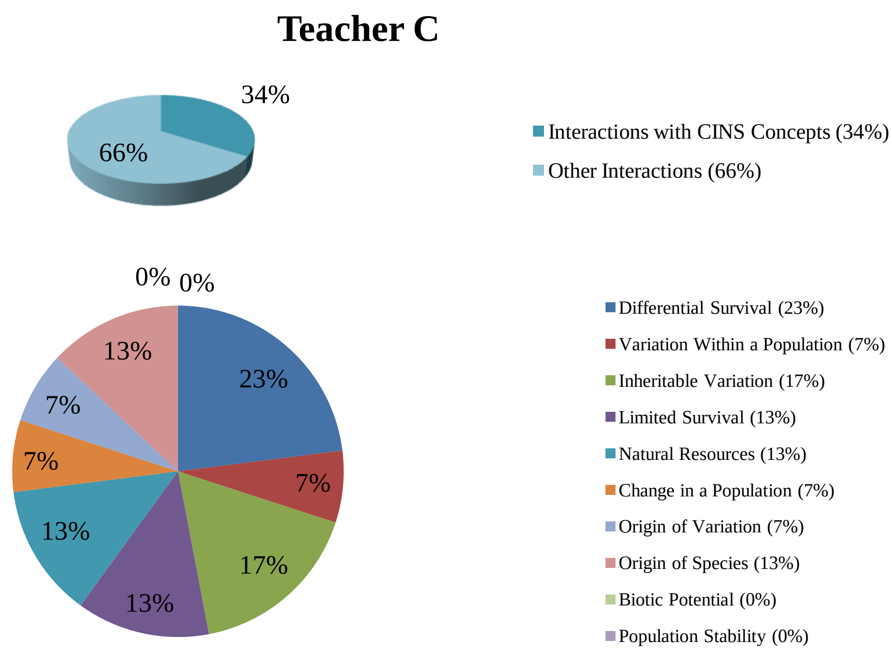


Figure 13: Percentage of Teachers A, B, D, and C's respective teacher-student interactions with and across CINS concepts during evolutionary instructional units. Smaller pie chart indicates each teacher's percentage of interactions with CINS concepts among his/her evolutionary interactions. Larger pie chart indicates each teacher's percentage of interactions with **specific** CINS concepts among his/her CINS interactions.

Overall results suggest Teacher B had her students engage with certain CINS concepts (e.g., *origin of species, inheritable variation*; see Figure 13) more than other concepts during her instructional unit. Using a variety of instructional strategies and questions (especially during her lectures when her students were taking notes), Teacher B had an approximate 125 different interactions with her students throughout her instructional unit. Of those interactions, approximately 40% (n=50) were devoted to CINS concepts. The same sort of trend appears with Teacher B's instructional activities as with her interactions. The CINS concepts of *origin of species* and *inheritable variation* appear more frequently with Teacher B's use of instructional activities (see Figure 12).

Similar to Teacher A, Teacher D's overall results demonstrate that her students engaged with almost all (with the exception of two, *biotic potential* and *population stability*; see Figure 13) of the CINS concepts in some form or another during her 10-day instructional unit. Quite methodical and purposeful with her strategies and questioning, Teacher D had an approximate 128 interactions with her students throughout her instructional unit and of those interactions, approximately 56% (n=72) were devoted to CINS concepts. Similar to her manner in determining how to interact with her students, Teacher D was also conscientious with which instructional activities her students engaged. Several of her interactions that involved instructional activities coincided with various CINS concepts (see Figure 12) and, like her colleagues, some of these concepts appeared more frequently (e.g., *differential survival, inheritable variation, variation within a population*) than others with the selection of these activities. The frequency of these concepts occurring with her instructional activities approximately matched the frequency of their occurrence with her total CINS concepts classroom interactions.

As a whole and throughout his instructional unit, Teacher C had approximately 88 interactions with his students on the topic of evolution. Compared with his colleagues, Teacher C's total interactions occurred less frequently. Of these 88 interactions, about 34% (n=30) specifically dealt with CINS concepts (see Figure 13). Recall that by choice, Teacher C never participated in common planning meetings with his colleagues. Whether it being due to his lack of participation in these meetings, uneasiness with evolutionary concepts, or by some other mechanism, there were substantially fewer CINS concepts found with the instructional activities of his evolutionary unit (see Figure 12) as opposed to his colleagues.

Teacher C's students' opportunities for participation with specific CINS concepts were rather isolated and occurred infrequently. When his students were engaged with other activities (i.e., watching selected videos, creating word clouds, presenting music videos), there was minimal teacher-student or student-student interaction with regard to CINS concepts. With the exception of *differential survival* and *inheritable variation*, Teacher C's students were not able to explore other CINS concepts with the various instructional activities. Moreover, the students were not able to explore these concepts on any deep conceptual level. The concepts were briefly mentioned with a few isolated teacher-student exchanges. When his students did receive opportunities to explore more concepts, the opportunities came all at once in a teacher-centered lecture toward the end of his instructional unit.

Suggestions for future classroom use. At the end of every teacher's instructional unit, each teacher (with the exception of Teacher D) was provided the opportunity to suggest how the CINS could be used in his/her classroom. The results reported here may provide a "starting point" for how the CINS could be adapted for use in a secondary school setting.

"Chunking" of information. Teacher A was vehemently opposed to having students complete the CINS all at once. She believed she would better use the information gained from her students if they would answer the questions over a period of several class meetings. She commented, "Maybe if they had done like each of the sections, like the finches, at one time and then something else at another time, that might have worked better for them (Teacher A, Post-instruction interview, 4/25/12).

Useful as a daily formative assessment tool. Teacher A also saw potential in the CINS's use as a daily formative assessment tool, especially when focusing on various evolutionary concepts. Since the CINS questions target different concepts, Teacher A said she could choose the questions she would want her students to answer according to the concept(s) she could be teaching on a particular class meeting:

> I think this would be a good way to like...I mean you could still do it as like a pre-assessment, but like before I talk about the finches, show them the finch part...kind of break it down to the concepts and then do it before each concept or before and after each concept...(Post-instruction interview, 4/25/12)

According to Teacher A, the different CINS questions could then be used as daily warm-up questions, much like the daily questions she had in place during her instructional unit:

> Yeah...'cause then like it would be good for like the warm-up the next day..."OK. Did they get it?" And look at it to see if they understood. And if they didn't, "OK. We've gotta go back and fix that." That would give me a better idea 'cause...in the class, in the moment, they'll go along with it and they'll seem to be following it, and then...you think, "Oh good! They totally got that today." And then you ask them the question the next day and they're like, "Huh?" And without that frame of reference, in the moment, they sometimes just don't have a clue. And so, that would be a good way to find out...did they really get it or...But that would be a good way to measure that. (Post-instruction interview, 4/25/12)

Some of Teacher A's rationale for her recommendations could stem from how much she thinks her students know about evolution. Since Teacher A believed her students knew very little about evolutionary concepts, her students' initial exposure to them needed to be "compartmentalized" so as not to be confused or muddled with other concepts:

> 'Cause I think they get confused. They can't always keep it straight. They're like, "Oh that's right. This is supposed to happen here and then you add something else." They're like, "Oh, but wait a minute. What about that?" They can't compartmentalize some of it. 'Cause I have kids that really struggle with that in big ways...'cause I mean I think...what did we talk about just before this? DNA and mutations…and they kept trying to like bring it back to something...I'm like, "No, no, no. This is different. This is separate." But they wanted to connect it to something else...and yes, genes were involved, but they didn't understand the way

> they were involved. And so some of them really had trouble trying to grasp it...it was a struggle for them. (Post-instruction interview, 4/25/12)

Therefore, according to Teacher A, exposing her students to many concepts all at once (like using the entire CINS as a pre-assessment) has the potential to confuse students. In her view, reinforcing the concepts separately and in isolation leads to more fundamental understanding. Furthermore, once that understanding is in place, the students will then be able to understand the inter-relatedness of the various concepts.

Diagnostic tool at beginning and after instructional unit. As mentioned previously, Teacher B welcomed the CINS in her classroom and believed she could adopt such an instrument as part of her classroom practice. Teacher B believed the CINS was best as a diagnostic tool, as both pre- and post-assessment. However, she felt it should be reduced to ten questions as opposed to twenty simply because of the time constraints of having her students try to read three passages and answer twenty questions in a 45-minute class period. In addition, she would treat the shortened CINS as timed quiz of sorts so that her students would be completely focused on answering a shorter set of questions. According to Teacher B, administrating the CINS in this manner would have more meaning to the students and allow more credibility with student results:

> But I would give it like ten questions…you've got this long to answer them, go. And that way, they kind of have to think right away...They're actually having to [answer] 'cause they're time-limited. And so...except for the few who are just going to circle whatever...you do have the few who go through and read it. And...then that way…you can use this information to see what they know and then post-, see what they learned. (Post-instruction interview, 4/25/12)

Like Teacher B, Teacher C also believed the CINS worked well as a pre- and post-test, but thought he would need other concept inventories for other biology topics in order to fully incorporate the CINS into his practice. By having different CIs for his use, Teacher C believed his students would then take the CINS even more seriously by considering what role their alternative conceptions have in their learning:

> And I think if the kids start...knowing that it's a pretest and they start getting used to that routine throughout the year, they're going to pay close attention to detail because they know they're going to have the same exact...exam, even though the first exam is difficult for them. They can start distinguishing their own misconceptions more readily 'cause they know what to expect. But to just introduce it all of a sudden…one time, they're not going to pick up, "Hey...I should have been paying attention to these all these weeks that we've been talking about this 'cause he's going to give us the same exam." (Post-instruction interview, 4/27/12)

Communication of results to students as teachable moments. While Teacher B heavily favored the CINS's use as a diagnostic tool, she also believed her students could benefit from having their overall results communicated back to them during the course of the instructional unit, especially as the students learn each concept.

> …'Cause I can always relay back to the test and say, "Remember on that test, when I was talking about the birds? Well, this is what we're going to get into." So...yeah...I could use it that way. Like a "remember when"...most of you might have answered this...well, this is what we're going to look into. (Post-instruction interview, 4/25/12)

According to Teacher B, doing so would allow her and her students to "dig into" the reasons why certain answers were chosen. Furthermore, the students could then relate to and engage with the CINS more after interpreting the results for either their class or other classes.

In a similar vein, Teacher C believed his use of the CINS could have been enhanced if he had shared his students' overall answering trends among his different classes. Doing so would have provided opportunities for his students to see how they were thinking about the different concepts and discuss the reasons why certain answer choices were more correct. Based on video and classroom observation data, Teacher C was partial to asking questions and engaging in discussion when his students were in a whole-class configuration. By having Teacher C's students to analyze the CINS data, there would have been different entry points for class discussion and his students would have been able to engage with these concepts in a conceptually deep and meaningful manner.

Summary. Since the CINS was such an integral component of the current study, the teachers may have had a heightened awareness of the concepts involved with natural selection, but this was not always the case. Granted, the teachers' units involved other evolutionary topics that were not specific to the CINS's topics, but Teachers A and D demonstrated efficiency with these natural selection concepts, with more than half of their total interactions with students from their units dealing with CINS concepts. Teachers B and C were not as efficient with their frequencies occurring below 50%. When examining the occurrence of a CINS concept, especially in the form of written questions or other tasks, Teachers A, B, and D's students received opportunities to make associations with these concepts 2-3 times more than Teacher C's students were able to do so, suggesting the three teachers who common planned together maintained a tighter adherence to natural selection concepts than did the single teacher who planned in isolation.

Certain CINS concepts were also stressed over others, with a stronger concentration on *differential survival* and *inheritable variation.* This result may be attributed to the teachers using "survival of the fittest" to help explain natural selection. Once this phrase was used, the teachers inevitably followed up with their students by asking them what was meant by "being fit" or "fitness". Also, the students' pre-test results on CINS questions dealing with *differential survival* were of special interest to some teachers. The CINS results may have guided the teachers to focus more on this concept. The concept of *inheritable variation* was introduced almost immediately after the students learned many genetics-related concepts. Since *inheritable variation* is closely tied to genetics, the teachers seized the opportunity many times to relate this concept back to a topic with which the students were recently familiar.

Ultimately, the teachers believed the CINS was a more progressive way to gain insight into what students are thinking as opposed to other traditional formal assessments with which they had experience. They could see themselves adopting the CINS in some form or another as part of their teaching practice, provided some modifications were made with it. Specifically, the teachers believed the CINS was too long and needed to be cut in half. Also, one teacher liked its use as a diagnostic tool and another felt she could use certain questions as a daily form of assessment on lessons that were focused on specific natural selection topics. Lastly, two teachers believed some opportunities for learning could be created if the overall answering trends were relayed back to their students. It was difficult for the teachers to describe the CINS's potential for use as anything else other than a test or a daily quiz. No teacher could describe focusing a lesson around a single reading passage or its associated questions.

Research Question #5: As measured by the concept inventory, do the teachers' respective students maintain or modify their alternative conceptions regarding natural selection?

Ultimately, a teacher's SMK and PCK for student ideas have an effect on his/her students (see Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013). While pilot study #2 and the current study did not set out to measure student outcomes as a result of whether or not each teacher modified his/her practice due to receiving knowledge about which alternative conceptions were common among his/her students, it was still imperative to determine which natural selection concepts gave students more or less difficulty.

	Concept	Teacher A	Teacher B	Teacher C	Teacher D	Average
#1	Biotic Potential	75%	69%	80%	67%	73%
#11	Biotic Potential	58%	46%	69%	41%	54%
#2	Natural Resources	63%	61%	66%	73%	66%
#14	Natural Resources	39%	29%	39%	34%	35%
#3	Population Stability	63%	56%	70%	68%	64%
#12	Population Stability	27%	31%	36%	28%	31%
#4	Change in a Population	12%	28%	20%	21%	20%
#13	Change in a Population	24%	35%	27%	22%	27%
#5	Limited Survival	65%	52%	49%	59%	56%
#15	Limited Survival	35%	22%	27%	34%	30%
#6	Origin of Variation	15%	13%	9%	13%	13%
#19	Origin of Variation	46%	34%	31%	37%	37%
#7	Inheritable Variation	61%	68%	45%	50%	56%
#17	Inheritable Variation	57%	46%	34%	39%	44%
#8	Origin of Species	26%	40%	42%	39%	37%
#20	Origin of Species	25%	39%	22%	21%	27%
#9	Variation w/in a Population	46%	41%	43%	37%	42%
#16	Variation w/in a Population	76%	71%	62%	66%	69%
#10	Differential Survival	37%	26%	29%	41%	33%
#18	Differential Survival	33%	24%	30%	39%	32%
Avg. # of Student Respondents on Post-Test		104	66	74	107	

Table 23: Percentage of student correct responses on CINS post-test grouped according to each teacher.

Table 23 summarizes the students' post-test CINS results for each concept and question according to each teacher. On a strictly descriptive basis, the students demonstrated an increased frequency of correct responses on most questions, when compared to their pre-test results (see Table 17). The CINS concepts of *biotic potential* and *differential survival* had the most dramatic increases, with an average 12 and 18 percentage point increase respectively. Most other questions had modest increases that ranged from 2 to 9 percentage points.

Even though Table 23 demonstrates dramatic gains with more students beginning to understand *differential survival*, Table 24 shows that this concept is still difficult for students to comprehensively understand. In fact, Table 24 shows that the majority of students in both pilot study #2 and the current study have difficulty with most CINS concepts. Nevertheless, the current study's students demonstrate overall improvement in understanding CINS concepts as compared to pilot study #2's students. However, the same three concepts (i.e., *change in a population, origin of species, differential survival*) that posed difficulty for the students in pilot study #2 exhibited the same trend for the current study's students.

Student Results (By Concept)					
Pre-Test			**Post-Test**		
Concepts	**% Correct Responses**		**Concepts**	**% Correct Responses**	
	Current Study (n=325)	**Pilot Study #2 (n=96)**		**Current Study (n=351)**	**Pilot Study #2 (n=90)**
Biotic Potential	52%	49%	Biotic Potential	64%	53%
Variation Within a Population	51%	47%	Variation Within a Population	56%	49%
Inheritable Variation	51%	40%	Inheritable Variation	50%	45%
Populations Are Stable	45%	34%	Populations Are Stable	48%	44%

Natural Resources Are Limited	42%	37%	Natural Resources Are Limited	51%	40%
Origin of Species	31%	20%	Origin of Species	32%	28%
Limited Survival	30%	28%	Limited Survival	43%	37%
Change in a Population	27%	25%	Change in a Population	24%	28%
Origin of Variation	23%	19%	Origin of Variation	25%	21%
Differential Survival	15%	18%	Differential Survival	32%	21%

Table 24: Comparison between current study and pilot study #2's student pre-/post-test CINS results arranged by concept.

Lastly, Table 25 summarizes the students' overall outcomes (including effect size) on the CINS grouped according to each teacher. According to Table 25, Teacher D, the novice of the group, had the largest effect size (0.77). She was followed by Teachers A and B, who were her frequent common planning colleagues. Teacher C was the only teacher who had no effect size, in that the knowledge his students had when they began the instructional unit was essentially the same knowledge they had when the unit was completed.

TEACHER	STUDENT OUTCOMES PRE-TEST	STUDENT OUTCOMES POST-TEST	EFFECT SIZE USING COHEN'S *d*
TEACHER A	39% (SD=13.6) N=86	44%* (SD=15.4) N=86	0.48 small to medium
TEACHER B	34% (SD=12.3) N=70	40%* (SD=14.9) N=70	0.40 small
TEACHER C	39% (SD=13.9) N=74	41% (SD=14.0) N=74	N/A
TEACHER D	34% (SD=15.6) N=73	44%* *(SD=15.0) N=73	0.77 medium to large

Table 25: Student outcomes on the CINS.
*Difference between pre-test and post-test significant at $p < .05$.
**$p < .01$

Chapter Seven: Discussion and Implications

Orientations Towards Science Teaching and Evolution

The current study investigated how the topic of evolution was taught by four biology teachers in the same science department at a high-needs high school. More specifically, the study inquired how these four teachers' practices were affected once they were formally made aware of their students' natural selection alternative conceptions through the use of a concept inventory. Each teacher's orientation to science teaching was gauged in order to get a sense of how student knowledge was used and valued within their individual practices. From the outset, one teacher was more didactic in her orientation to science teaching and took a "student is an empty vessel" approach to all lessons. One teacher was more student-centered in his approach, but acquired a more didactic, teacher-centered orientation when he noticed his students were not achieving the desired learning outcomes. Lastly, two teachers described themselves as being in the middle of this teacher/student-centered continuum by trying to maintain a balance of student-centered hands-on activities with teacher-centered lectures. However, this balance became skewed toward the teacher-centered direction as their evolutionary instructional units progressed.

It was certainly necessary to also gauge these teachers' orientations to the topic of evolution since this entire investigation was conducted within the context of teaching evolution. Previous research has certainly demonstrated that a variety of factors play a role in how evolution gets taught. These factors include personal feelings (e.g., Brem et al., 2003), inadequate preparation (Aguillard, 1999; Griffith & Brem, 2004), or some combination of personal emotional stress and negative perceptions surrounding evolution (Brem et al., 2003; Griffith & Brem, 2004).

The results from Brem et al. and Griffith and Brem were certainly seen in the current study. Three of the 4 teachers were advocates of evolution and one of those 3 believed some sort of acknowledgement of the evolution and religion controversy was necessary in order to set a classroom climate of non-controversy. The fourth teacher was seemingly an advocate for evolution, but expressed doubts with evolutionary processes that occurred at the molecular level. As a result, these doubts may very well have been acquired by this teacher's students during the instructional unit through various class discussions and other forms of discourse. This particular teacher believed it was necessary for his students to question evolution and how it works. In essence, he was exposing his students to all positions—scientific or not (although he may have believed the non-scientific positions were actually scientific). He explained to his students that he wanted them to make up their own minds based on their own beliefs or research, and not based on what he or some textbook said. He expressed great confidence in his students deciding for themselves. However, there are those that doubt a 15-year-old student has enough information to reject thousands of peer-reviewed scientific papers that have established evolution's credibility (Berkman & Plutzer, 2011). This all positions approach may send the wrong message to students, where they may begin to think that very well-established scientific concepts can be debated in the same way personal opinions are debated (Berkman & Plutzer, 2011).

These four teachers' images of ideal science lessons lent verification of the teachers' science teaching orientations. All four teachers described situations where they wanted their students to take the direction of their science lessons, but in different magnitudes. Three of the four teachers wanted to have some sort of teacher- and student-directed balance, and the fourth teacher envisioned a more complete student-centered environment. Nevertheless, the ideal image of these four teachers' science lessons fell by the wayside when time and curricular constraints entered the picture.

The tension between teaching ideal science lessons and dealing with concept-heavy curricular demands is not a new phenomenon. However, the school district's placement of evolution as a two-week unit in the middle of the spring semester did not alleviate these teachers' pressure to move on to the next instructional unit, especially with the state assessment looming in front of them. Indeed, the entire mode of standardized testing continues to contribute to the idea of a disjointed science curriculum (Settlage & Meadows, 2002). A topic as misunderstood as evolution needs for students to participate and engage in thoughtful instructional activities, especially those that facilitate the understanding of NOS concepts. Furthermore, if school districts insist on having teachers teach instructional units as isolated topics, then evolution's placement as a curriculum topic needs reconsideration. Scientists view evolution as the conceptual foundation of biology, but evolution's importance becomes diminished when it is relegated to a single unit that is taught in 10-12 days or less. Since the study site's district curriculum writers do not emphasize the thematic teaching of major scientific concepts, these biology teachers must be provided with more support to fully integrate and unify evolution with the disparate topics in biology. Otherwise, these biology teachers and others in the district will continue to be left to their own devices and preparation in ensuring evolution is taught properly.

Using Prediction Accuracy as a Means to Measure Teachers' Knowledge of Student Ideas

While the current study did not seek to measure a teacher's entire PCK where evolution was concerned, it did present a potentially powerful method for gauging and describing one of PCK's components--knowledge of student ideas/areas of student difficulty. A procedure needed to be in place that could sensitively and accurately capture this key teacher characteristic, and having a method that operationalized the teachers' predictions of their students' alternative conceptions within this context was critical.

The prediction accuracy operationalization procedure described in the Methods section provided insight into how this group of teachers thought of their students' alternative conceptions. In fact, there is recent precedence for having a prediction task of this nature to measure this aspect of a teacher's PCK (e.g., Sadler et al., 2013). However, the procedure used in the current study requires further modification if it is to be used on a larger scale. It was left up to the teachers whether they made single or multiple predictions on each question and the results showed that Teacher C made the most multiple predictions. One might assume that this multiple predicting may be the result of being unsure about how a teacher's students will answer; but the prediction accuracy procedure allowed for demonstrating that this may not be the case, as evidenced by Teacher C's prediction accuracy with multiple predictions. If a teacher had predicted all answer choices for a particular question, follow-up questioning would be necessary (i.e., rationale for choosing all answers, estimating the distribution of student answers).

In a similar fashion, prediction accuracy needs to be quantified if a teacher does not make a prediction, that is, when he/she predicts his/her students will have no difficulty with a question. At the moment, these non-predictions made by teachers are not counted towards the prediction accuracy measure, but they need to be counted because a teacher who makes a non-prediction on any question reveals just as much insight as one who makes very specific predictions. In any case, standardizing the procedure (e.g., relaying to a teacher how many answer choices he/she may predict on each question, or asking a teacher to estimate the percentage of his/her students who may answer each option) will help in decreasing the amount of ambiguity that may be currently present with some of the predictions.

Predicting student alternative conceptions was a deeply reflective task for this group of teachers. Teachers do not often receive the opportunity to think about and consider their students' alternative conceptions when planning for lessons. In fact, because daily routines occupy a considerable part of a teacher's practice, teachers often need to be reminded to engage in this sort of thinking about their students' conceptual understanding. As mentioned previously, teachers need to be afforded opportunities with which to engage in student thinking and alternative conceptions. Having these opportunities may enhance this aspect of their PCK and eventually, student learning outcomes. Research into this line of inquiry may provide further insight into the complex aspects of PCK.

Student Alternative Conceptions Used as Resources for Learning

While all four teachers valued prior student knowledge that was correct, they did not quite know how to continue to probe for student alternative conceptions. This finding is consistent with results from earlier studies (e.g., Morrison & Lederman, 2003; Davis et al., 2006; Otero & Nathan, 2008). Teacher questioning was the most common means for probing student thinking in the current study. However, student thinking was not explored to its fullest extent. Many questions probed for factual recall of definitions and concepts, and students rarely received opportunities to offer explanations for specific evolutionary processes. When student alternative conceptions did become apparent, the teachers either corrected or did not acknowledge them, similar to findings from Otero & Nathan (2008). This lack of teacher follow-up with alternative conceptions may be attributed to the teachers' science teaching orientations as a whole. The majority of the teachers did not emphasize student ideas as a large component of their ideal science lessons. Teacher C, in fact, described the most student-centered learning environment, and had more occurrences of exploring student thinking, but unfortunately, many of these occurrences were related to the non-scientific aspects of evolution. Even when the principal researcher brought student thinking to these teachers' attention in the form of recognizing student ideas on the CINS, exploring student thinking was still not a priority.

This lack of student-centered awareness has implications for how common planning time is structured and the types of professional development (PD) teachers, like the individuals in the current study, are receiving. Unstructured common planning meetings do not maximize teachers' full potential as intellectuals and reflectors of their own practices, especially when the time is being used for procedural activities, such as arranging supplies and equipment for other classes in the day. Grading student work is also a popular activity during unstructured meetings. If there was a set of suggested guidelines to follow and goals to attain for common planning meetings, teachers may receive more benefit from them. Possible activities during such meetings could include a closer examination of the type of intellectual work students are asked to do when completing assignments. Teachers may also examine if such assignments are adequately designed to demonstrate student learning of scientific concepts. Future investigation into this line of inquiry may yield positive outcomes for both teachers and students.

Teachers' participation in professional development (PD) that examines the identification and resourcefulness of student alternative conceptions may also be a fruitful venue for future research. All four teachers reported never having participated in PD that centered on the teaching of evolutionary concepts. Instead of these teachers receiving another PD session on the latest round of data mining exploration of state assessment results, the teachers could benefit from an examination of various classroom discourse practices that focus on the identification of alternative conceptions and other student ideas. This sort of PD could be implemented particularly through the use of video. Given its situated nature, video (along with other classroom artifacts, such as lesson plans and student work) can provide an effective context for teacher learning during PD (Borko, Jacobs, Eiteljorg, & Pittman, 2008; Putnam & Borko, 2000).

Theoretical Implications

In light of the current study's results, it seems appropriate to return to discussions regarding integrative and transformative models of PCK and SMK. The integrative model included SMK within PCK and the transformative model retained SMK as a separate knowledge base component. Integrative models remain popular because they encompass a teacher's wide range of skills and knowledge, but transformative models are equally as important because they tend to focus on subject-specific PCK. In addition, transformative models seem more useful for science education because they closely examine issues that are specific for a particular scientific subject, including how to teach conceptually difficult and abstract ideas (Kind, 2009a). Magnusson et al.'s (1999) transformative model of PCK and SMK offered a useful theoretical background for the current study, in that it implied a mechanism was involved with a teacher's possession or lack of PCK, and the current study's results offers continued support for a transformative model of PCK .

While all five components of Magnusson et al.'s model were not explicitly investigated during the course of the current study, they certainly offer the potential for teachers a way to further develop their PCK within different contexts and settings by using a variety of instructional approaches and assessment strategies.

A qualitative study of this nature certainly demonstrates that relationships between different aspects of science teacher knowledge are complex and dynamic. While particular aspects remain relatively stable within a teacher's practice, other aspects are more tenuous and prone to continual re-shaping, thereby having an increased or decreased effect on other aspects. With its results and findings from a core group of science teachers, the current study attempted to describe some of the relationship dynamics of science teacher knowledge of evolution, with regard to the PCK areas of science teaching orientation and knowledge of students' alternative conceptions with subject matter knowledge and personal beliefs (SMKPB).

Adopting the perspective that the SMKPB of a topic is a separate area of the teacher knowledge base that exerts some influence on PCK, Figure 14 displays a representation of how SMKPB is impacting certain areas of the teachers' PCK for evolution. First, findings from the current study revealed that the teachers' SMKPB tended to act independently from the knowledge of their students' alternative conceptions. The teachers' SMKPB may have played some role in possessing this sort of knowledge, but not enough to describe a truly strong connection. As recalled from the teachers' results (i.e., prediction accuracy of CINS questions answered correctly/incorrectly by the teachers), their prediction accuracy of the students' alternative conceptions remained relatively constant, and with several questions, reached the maximum value. Even the teachers' prediction accuracy among the individual CINS questions answered incorrectly was >.75 in the majority of the cases.

Second, the teachers' results revealed more of an interchange between their SMKPB and PCK's orientation to science teaching as opposed to their knowledge of student ideas. The teachers made some attempts to realize their ideal images of science teaching during the course of their evolutionary units, but ultimately fell back to what they knew to be familiar and comfortable, which was a teacher-centered mode of instruction. In spite of the teachers demonstrating more or less proficiency with evolutionary concepts, they did not seem to ultimately shift their individual orientation towards science teaching. The converse of this relationship can also be stated for this group of teachers. The teachers' orientation towards science teaching continued to drive their instructional units forward, no matter what their SMKPB may have been for evolution.

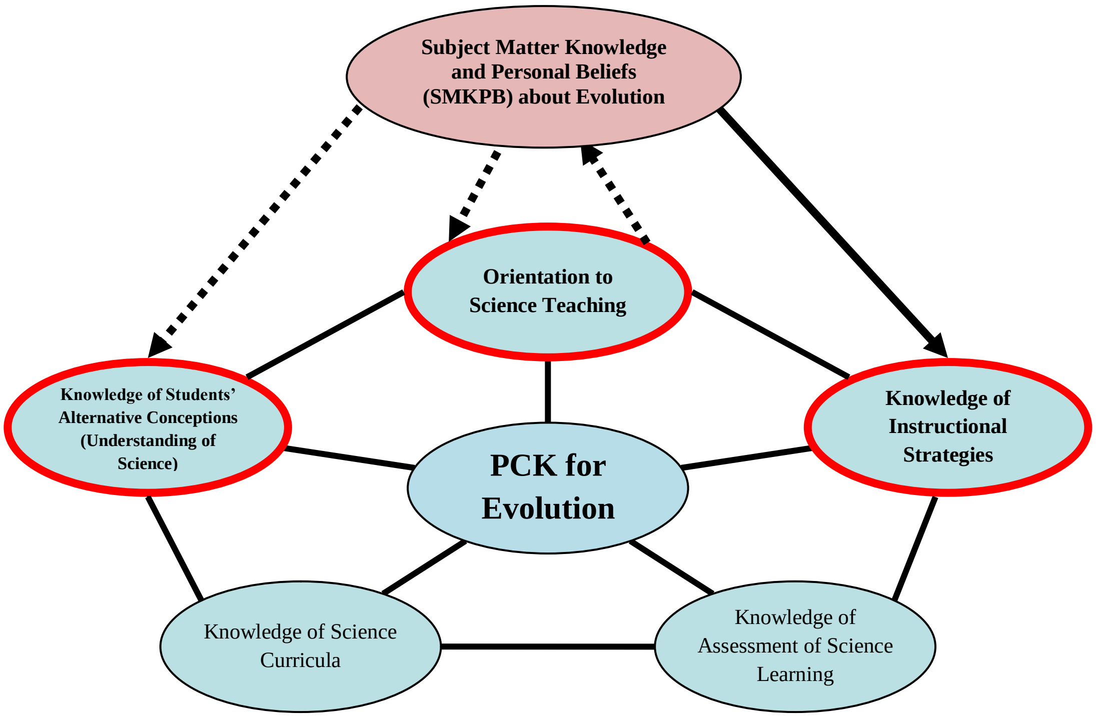


Figure 14: Representation of relationship between SMKPB and specific areas (outlined in red) of PCK for teaching evolution using Magnusson et al.'s (1999) model.

Lastly, it was apparent that SMKPB had a greater influence on these teachers' instructional practices than on other PCK areas that were investigated. However, when discussing the nature of SMKPB for teaching evolution, it is necessary to examine this construct more closely and tease apart both SMK and personal beliefs (PB) because they both affected the types of instructional strategies the teachers used. Teacher A and Teacher D had the highest scores on the CINS and promoted the least amount of misconceptions during their instructional units. Even though they maintained a rather teacher-centered mode of instruction, they were relatively consistent with their students' learning goals and objectives. On the other hand, Teachers B and C were both more inconsistent in their lesson planning and with maintaining the overall "vision" of the evolutionary concepts their students were learning (i.e., unconventional sequencing of lesson topics, a "rush" to cover many concepts towards the end of the instructional unit).

Nevertheless, some of the teachers' PB may be interacting with their SMK, resulting in an effect on their instructional strategies. In accordance with Griffith and Brem's (2004) teacher categories for perspectives on evolution, the current study's teachers tended to fall into one of three categories: "'Conflicted,' who struggle with their own beliefs and the possible impact of their teaching; 'Selective,' who carefully avoid difficult topics and situations; and 'Scientists,' who see no place for controversial social issues in their science classroom" (p. 791). Teacher C was firmly placed in the "conflicted" category, and his PB became apparent during his instruction with the use of his student questioning and introduction of his PB as a discussion topic. Teacher C questioned certain evolutionary concepts and its epistemology as a scientific process and some of this doubt may have transferred to his students.

Teachers A and D, on the other hand, were more firmly planted in the "scientist" category. As previously mentioned in the Results section, issues with religion and controversy were never discussed in the course of their instructional units. Evolution is science and it was treated as such by these two teachers. Teacher B also had this perspective, but was compelled to address the "controversy" in an effort to maintain an open dialogue with her students. Therefore, it is more difficult to categorize Teacher B, as she never appeared to be "selective" in addressing religious issues; and yet, maintained a "scientist" perspective, even though she did address religious issues. From the perspective of advocating for evolution, these three teachers' never wavered. In turn, their students saw evolution being treated like any other science topic.

Issues for the CINS's Use at the Secondary Level

With regard to the utility of the CINS as a classroom tool, certain trends and themes are evident with all four teachers and the PCA described earlier in Chapter 5. However, some discrepancies appear as well. This section describes and explains these findings.

Useful tool for seeing what students understand. All four teachers considered the CINS a strong instrument for measuring what their students did and did not know. In some cases, the teachers themselves were taken aback with some of the CINS questions and had to take significant time exploring other answer options. The three teachers with more experience (Teachers A, B, and C) all believed the information they received from the CINS regarding their students' alternative conceptions was much more useful and practical than any state assessment could ever relay. It is worth noting that the three experienced teachers made this same observation, while the novice (Teacher D) did not. This common observation may stem from a sense of test weariness, in which the experienced teachers have been given so much data on their students that does not seem helpful and seen many test questions from both practice and released state tests that do not necessarily measure conceptual understanding (NRC, 2001). They welcomed an assessment with a different approach to probing student understanding. Whatever information they gained from the CINS, they knew it could potentially be helpful in a practical sense. Since Teacher D was still a first-year teacher, she had not received as much exposure to the full test machinery of the school and district as her colleagues had. Therefore, she may have had little with which to compare the CINS.

Concentration of concepts. It is not surprising that all four teachers focused more heavily on *differential survival* and *inheritable variation* as opposed to some of the other CINS concepts. Since *differential survival* dealt directly with biological fitness, all teachers may have believed that this was a foundational concept for their students understanding natural selection. As a result, it received more prominence throughout each teacher's instructional unit. Teachers A and D, in particular, were keenly interested in their students' pre-test performance on this concept and used the CINS results to their advantage. Many teacher-student interactions stressed biological fitness and what it meant to the students. Whether the interactions consisted of students simply recalling what fitness was or directly confronting the alternative conception that biological fitness deals with strength and size, all four teachers made *differential survival* a focal point of emphasis.

Inheritable variation was another CINS concept that was continually emphasized and stressed among the four teachers. *Inheritable variation* dealt with organisms' different adaptations and how traits were passed from one generation to the next. The topic of genetics had been taught by all four teachers directly before evolution and since *inheritable variation* was closely related to genetics, this concept seemed like a natural segue to and consistent thread during their evolutionary instructional units. By continually emphasizing *inheritable variation,* the teachers found this to be an effective way to see how well their students had learned genetics concepts.

Strategic use of students' CINS results. While all four teachers were made aware of their students' natural selection alternative conceptions by using the CINS, each teacher took away the information that was most useful to them. For example, Teacher B's student data from the CINS pre-test was of specific diagnostic value to her and this may have been in part due to Teacher B facing increasing departmental pressure with completing her instructional unit by a particular date. She was behind her colleagues, Teachers A and D, and felt she had to "rush" through her instructional unit. Therefore, analyzing her students' performance on various CINS questions may have played a role in guiding the planning for her unit. This may explain why Teacher B applied more resources and instructional strategies to a CINS concept such as *origin of species* (a concept with which her students exhibited difficulty on the pre-test) and fewer on *biotic potential* (a concept with which many students had less difficulty).

In most of the teachers' cases, strategically useful information dealt with the concept of *differential survival.* Even though the rest of students' results for other concepts may have seemed interesting and/or surprising, these results did not necessarily play a direct role in the teachers' lesson planning. Out of the many classroom observations, daily interviews, and common planning meetings with the teachers, there were very few isolated instances of the teachers mentioning the students' results on the CINS. This lack of attention may have been attributed to the presence of other evolutionary topics that had to be included in the teachers' instructional units that were not specifically related to CINS concepts, such as evidence for evolution. In addition, this inattention may have stemmed from not fully seeing the ten CINS concepts as part of an integrated bigger picture and this sort of reasoning may explain the concern for superfluous concepts on the CINS.

Collaborative use of ideas and resources versus solitary planning. From the department's perspective, common planning time was viewed as a time when the teachers from different disciplines could meet as a group to share lesson planning ideas and resources. While the department did not mandate meeting every day, the teachers were encouraged to meet at least two times each week. I observed and recorded five different common planning meetings through the duration of the study. All meetings had Teachers A and D as the principal participants. Teacher B would frequently attend as well, but her attendance was less constant, as she was slightly behind Teachers A and D in terms of topics she was teaching. As mentioned previously, Teacher C never attended common planning meetings.

The collaborative bond shared by Teachers A, B, and D seemed to have an effect on the way the CINS concepts were used in the classroom. Both Teachers A and D were rather efficient with how they engaged their students with CINS concepts. These two teachers were in contact every day with each other, even if it was just to discuss how their respective lessons were progressing. Teacher B was efficient to a lesser extent, and Teacher C exhibited the least engagement. The relationship between Teachers A, B, and D extended even to how the CINS could be used for future use. These three teachers were very used to assessing their students in some form or another at the beginning of almost every class. Therefore, it is not surprising that Teachers A and B (there is no data for Teacher D here) could see themselves easily adopting the CINS as a form of gauging students' knowledge since this practice is part of their respective routines already. However, Teacher C's case was different. Since he rarely probed student understanding of these natural selection concepts on a daily basis, he had a more difficult time envisioning how he could use the CINS.

CINS demonstrates inconsistency with PCA results. The results of the current study's PCA demonstrate some support for the internal validity of the CINS's underlying measurement structure. This is a bit of a contrast to Anderson et al.'s (2002) original study, in which "strong support" was demonstrated for the inventory. If the eight components on the current study's PCA represent distinct evolutionary concepts, then only one component contained a single set of question pairs that represented one concept (*change in a population*). Therefore, it seems that some of the concerns about the CINS that were relayed with Nehm and Schonfeld's (2008, 2010) findings apply in the current study's context as well.

Most other components revealed where questions intended to measure different concepts were actually similar to each other. Component 1 contained questions 16 (*variation within a population*) and 17 (*inherited variation*). A closer examination of these two questions reveals that they are related to each other in the respect that they both occur towards the end of the assessment and ask about features or traits of the Canary Islands lizard population. While question 16 was intended to ask about the variability of certain traits and question 17 was intended to ask about how such traits were passed down from generation to generation, it is entirely reasonable that a high school student sees these concepts as being very closely related. Many traits manifest themselves as physical characteristics and these traits are inherited from parents. Also, some student may have resorted to guessing for the answers to these questions as these questions appear towards the end of the assessment.

The same sort of related rationale can be used for questions 2 *(natural resources)* and 5 *(limited survival)* which were both contained in component 3. Both questions had very similar wording in that they asked about the relationships between the Galapagos finches and their food supply. Many of the students most likely viewed these particular questions as practically indistinguishable from each other and may have been reacting to the surface level features of these questions rather than any deep conceptual understanding. Follow up questions with a sample of students would be required to corroborate this claim, but for the moment, it remains a reasonable hypothesis. Anderson et al. revealed a similar finding in stating, “This is not surprising because when students understand that there is a competition for resources, they acknowledge that some individuals die” (p. 968).

In a similar vein, the current analysis showed that questions 1 *(biotic potential)* and 15 *(limited survival)* were both contained on component 5 (which seems to be related to the aforementioned component 3). Question 1 was designed to assess a student’s understanding of how populations would grow if there were ideal conditions, that is, no predators and unlimited food. Question 15’s scenario of predicting what would happen to a population when the food supply was limited was the exact opposite in nature. Therefore, students may have viewed these two questions as being very similar to one another because of the questions’ inherent opposing realities—when a population has an unlimited food supply, it thrives and when food becomes scarce, individuals begin to starve and die.

The other two questions which were found on a single component were questions 6 *(origin of variation)* and 18 *(differential survival)*. These two questions were contained in component 8, and it is unclear as to why these they clustered together. Question 6 asked about how different finch beak types may have appeared on the Galapagos Islands, whereas question 18 dealt with notions of biological fitness. These questions appear to be assessing two distinct ideas, but there is some indeterminate relationship between these two questions for this population of students.

There were two instances in which three different questions were contained on a single component. In one case all three questions were designed to be assessing three separate natural selection concepts. Questions 9 *(variation in a population)*, 11 *(biotic* *potential),* and 12 *(population stability)* were all contained in component 2. Such an instance never occurred in the original study's PCA. These three questions all used the context of the Venezuelan guppies to assess the seemingly different concepts. Questions 11 and 12 are more related to one another in the sense that, like the situation mentioned above with questions 1 and 15, one question describes a scenario where there are ideal conditions for a population to grow (question 11) and the other question describes a more realistic setting where there are predators that threaten population expansion (question 12). Question 9, which describes the overall features of the guppy population, is more peripherally related to questions 11 and 12. Nevertheless, students may have gleaned from question 9's answer choices that the population's characteristics certainly have an influence on certain members' survival when they are faced with predators. As a whole, these three questions were tied to the entire theme of population dynamics, and the variability of a population is a strong determinant of how a population fluctuates or remains the same.

The next case which had three questions load strongly on a single component was a bit different from the previously mentioned case in that two of the questions (questions 4 and 13) represented a pair that was originally designed to assess one concept—*change in a population*. Question 7 *(inheritable variation)* was the third question that was contained in component 4. Questions 4 and 13 described scenarios from two different contexts (i.e., Galapagos finches and Venezuelan guppies) and probed for the main changes that occur in a population over time. The answer choices of these two questions used genetics-inclined language (e.g., "traits", "passed on to their babies", "mutations") and this may explain why the students related these questions to question 7. Question 7 also dealt with the Galapagos finches and directly asked what type of variation was being passed on future finch populations. The students may have reasoned that only genetic variation can be inherited and the main mechanism by which changes can occur in populations is through inheritance.

There were four questions which were not contained in any component: questions 8 *(origin of species)*, 10 *(differential survival)*, 14 *(natural resources)*, and 20 *(origin of species)*. Questions 8 and 20 probed for understanding of origin of species and this may have been a case of the students truly having a limited awareness of how different species arise. Indeed, when Teacher C asked his students what their thoughts were about the origins of plants on an island, many students were unable to offer any explanations, and those that did offer an explanation claimed some “force” or “something in the soil” made the plants appear. In Texas, the concept of speciation is not fully realized until high school. In fact, there is minimal mention of speciation in the elementary and middle grades according to the state standards. Question 14 dealt with the availability of food for the Canary Islands lizards. However, when taken and read independently, the question suggests an understanding of the food supply on the Canary Islands may be required in order to correctly answer the question. Since the students had never heard of the Canary Islands, they may have believed it was impossible to correctly answer the question if one had no familiarity with the food supply dynamics of the Canary Islands. Lastly, it is unclear why question 10 was not contained in any component. Question 10 probed understanding of biological fitness and was intended to detect any alternative conceptions that dealt with strength, size, speed, and agility. Further exploration into this question and its counterpart (question 18) will be needed in order to see how these items can be improved for future use.

Limitations

The current study's results indicated teachers' SMK and PCK for evolution was detected from different classroom interactions through a variety of situations. While it is established that knowledge and awareness of student ideas is an important aspect of PCK, the current study demonstrates why this area of PCK is important. PCK is a challenging construct to understand because it remains elusive at times, in that experienced teachers do not always feel the need to articulate their practices and novices do not often have strong ideas of what is involved with teaching. Nevertheless, as Kind (2009a) describes, "the attraction of PCK lies in its ability to tell us something of the unique professional experience that constitutes teaching" (p. 30).

The set of studies reported here had several limitations. First, the group of teachers involved with the current study was entirely different from the group that was involved with pilot study #2. It may have been possible to study the teachers' practices on a longitudinal basis since the study site was the same for both studies. However, class scheduling and the resignation of one teacher from pilot study #2 made this aspiration impossible. Second, while a sample size of 4 teachers in the current study is certainly adequate for conducting a qualitative study of this nature, one may mention that it may be difficult to generalize across experience and SMK levels of the entire biology teacher population. However, there is no reason to suggest that a similar group of teachers in a school like Tobin HS would demonstrate drastically different results. Nevertheless, this line of research inquiry would be further supported by investigating a group of teachers in a different context (e.g. 90-minute block scheduling or no common planning meeting time). Furthermore, a sampling of teachers in different settings would be needed to confirm and further investigate the relationship aspects found in the current study between SMKPB and PCK for student ideas/areas of difficulty. Next, the current study's teachers' practices were investigated just within the context of evolution. There was not another topic within biology (e.g., genetics) with which to compare the teachers' PCK.

Next, with regards to the CINS, neither pilot study #2 nor the current study probed students' thinking further through the use of follow-up questioning or think-alouds. In a sense, this procedure was not necessarily keeping with the nature of pilot study #1 where students' thinking was continually probed. However, the intention with the latter two studies was to gauge the CINS's utility by having a large number of students answer its questions and discover overall trends. Still, more insight with the CINS's validity on the current study's population would have been gathered had a random sample of each teacher's students been asked follow-up questions and participated in think-alouds about the answers they chose.

Besides the previously mentioned concerns about CINS, there are also issues with its administration during the current study. I was not present at every teacher's administration of the CINS (either pre-/post-test) to his/her classes. A substantial number of students may have struggled with the CINS's reading passages and resorted to guessing on some questions Also, it was possible that any of the teachers may have provided key information about any of the questions to his/her students and resulted in inaccurate measures of student knowledge. Any of these occurrences may have explained why some of the teachers' classes exhibited wide variation with answer choices; thus resulting in the teachers' very limited or strategic use of the information provided by the CINS.

Lastly, the data analysis presented here, especially with regards to coding, was solely done by me. Initial justification for this decision originated with the fact that I was particularly familiar with how the teachers conducted their lessons and the sequence in which they had been taught. Providing this instructional context to an independent coder is an essential step so that he/she knows how to effectively code. For example, an additional coder would need to know which concepts had already been introduced within the context of each teacher's instructional unit so that he/she will then know when to code for the occurrence of question that probes for an alternative conception as opposed to one that simply asks for the recall of a definition. Nevertheless, steps are being taken to ensure inter-rater reliability of the current study's data, as another individual (a doctoral student studying evolution education) is currently coding a portion of each teacher's classroom transcripts.

APPENDIX A

TABLES AND FIGURES FOR PILOT STUDIES #1 & #2

Lesson Title	Tasks/Assignments Used for Coding
Lesson #1: The Nature of Scientific Arguments	Task #2--Making Sense of Past Events: Describe one decision (inference) your group made about the order of the cards in terms of the data (observations) you used and the prior knowledge and beliefs (PKBs) you brought to bear in developing the sequence of cards. Tasks #3A-C--Identifying Data, Inferences, and PKBs: Write down two references to data from Attenborough's writing (A). List two inferences that are included in the passage (B). For each of the inferences you identified previously, list at least one PKB that was used to make that inference (C).
Lesson #2: The Nature of Explanatory Models	Tasks #4A-C: Provide an explanation of how Darwin/Lamarck/Paley would account for the presence of numerous pigeon varieties within what is traditionally a single species.
Lesson #3: Adaptation	Task #5--What do you think the word "fitness" means? How close or far off was your definition from biologists' definition of "fitness"? Tasks #6A-B: Construct a(n) individual/group definition for "adaptation".
Lesson #4: Natural Selection	Task #7--During the simulation, what trends/patterns did you observe with camouflage and visual acuity? Provide a hypothesis as to why this happened. Task #8--How is extinction related to population size? Explain this relationship in terms of variability and the kinds of places [these populations] tend to be found.
Pre-/Post-Assessment	Tasks #1 & #9--How might a scientist explain how tortoises with a 'saddleback' carapace came to be? Please give a detailed explanation.

Table 1: Lesson sequence overview and specific tasks/assignments used for coding in pilot study #1.

Pre-/Post-Assessment for Pilot Study #1: Galapagos Tortoises

The Galapagos Islands are home to giant tortoises that feed on green vegetation. Originally, tortoises lived only on Isabela Island and had dome-shaped carapaces, or shells (see figure 1). Isabela has a relatively wet climate and varied plant life. Today tortoises are found on the other islands as well. On the small islands such as Española (Hood), there are tortoises that have a 'saddleback' carapace (see figure 2). The 'saddleback' carapace is elevated above the neck and flared above the hind feet. On the small islands the climate is drier and there is almost no ground vegetation. Prickly pear cactus (a major source of food and water for the 'saddleback' tortoises) has a tree-like form; the woody trunk holds fleshy green parts of the plant high off the ground.

Using the information provided here and in the following figure, please give a detailed explanation for how a scientist might explain how tortoises with the ‘saddleback’ carapace came to be.

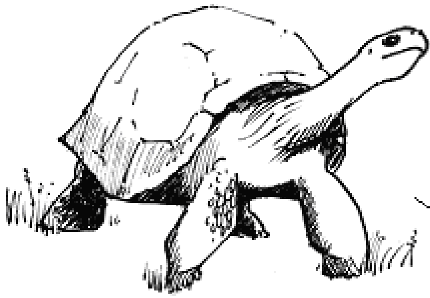


Figure 1: Domed Tortoise

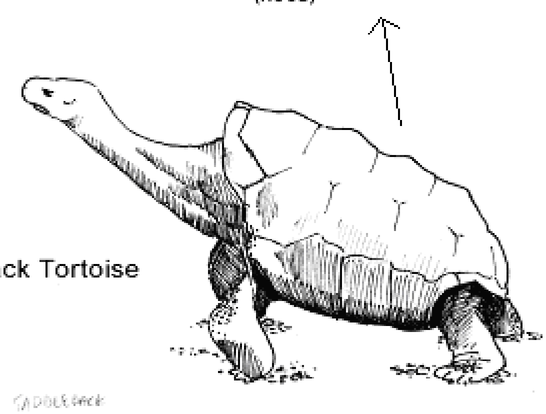


Figure 2: Saddleback Tortoise

APPENDIX B

CLASSROOM OBSERVATION INSTRUMENT--ADAPTED FROM MORRISON & LEDERMAN (2003)

TEACHER: ____________________________________

PERIOD: __________________________

Questioning Strategies

a. Teacher (T) asks for explanation (EXPLANATION) Occurrences_______ Notes:
b. T asks for clarification (PROBE) Occurrences_________ Notes:
c. T asks for predictions that show alternative conceptions (PREDICT) Occurrences______ Notes:
d. T asks questions (Qs) directly to elicit students' (Ss) alternative conceptions (ALTERNATIVE CONCEPTIONS) Occurrences________ Notes:
e. T asks for recall of facts or definitions (RECALL) Occurrences________ Notes:
f. T asks open-ended Qs with many correct answers (OPEN-ENDED) Occurrences_______ Notes:
g. T asks about Ss prior experiences (EXPERIENCES) Occurrences________ Notes:
h. T asks about Ss prior knowledge (PRIOR KNOWLEDGE) Occurrences_________ Notes:
i. Ss alternative conception not recognized by teacher (NONRECOGNITION) Occurrences________ Notes:
j. Other (MISC) Description:

Student to Teacher Questioning

a. Ss asks a Q (STUDENT Q) Occurrences________ Notes:
b. Ss asks a Q that shows an alternative conception (STUDENT Q w/ ALT CON) Occurrences________ Notes:
c. Ss asks for explanation (MISUNDERSTANDING) Occurrences________ Notes:
d. Ss asks for clarification (CLARIFICATION) Occurrences_________ Notes:
e. Ss asks for individual help (INDIVIDUAL) Occurrences_________ Notes:
f. Other (MISC) Description:

Teacher Presenting Information

a. Straight lecture (LECTURE) Occurrences________ Notes:
b. Demonstration (DEMO) Occurrences_________ Notes:
c. Text work (TEXT) Occurrences __________ Notes:
d. T uses scientific concepts to explain phenomena (SCI CONCEPTS) Occurrences_______ Notes:
e. T contrasts Ss alternative conceptions with scientific concepts (CONTRAST) Occurrences________ Notes:
f. T uses discrepant event to uncover alternative conceptions (DISCREPANT E) Occurrences________ Notes:
g. Class discussion in which Ss ideas are elicited (DISCUSSION) Occurrences_________ Notes:
h. Other (MISC) Description:

Written work

a. Pretest (PRETEST) Occurrences__________ Notes:

b. Writing Prompts (PROMPTS) Occurrences__________ Notes:

c. Concept Maps (MAPS) Occurrences_________ Notes:

d. Worksheet (WORKSHEET) Occurrences__________ Notes:

e. Quiz (QUIZ) Occurrences_________ Notes:

f. Lab Write-up (LAB REPORT) Occurrences__________ Notes:

g. Exam (EXAM) Occurrences_________ Notes:

h. Other (MISC) Occurrences_________ Notes:

APPENDIX C

CONCEPTUAL INVENTORY OF NATURAL SELECTION—MODIFIED FROM ANDERSON, FISHER, & NORMAN (2002)

Your answers to these questions will assess your understanding of the Theory of Natural Selection. Please choose the answer that best reflects how a biologist would think about each question.

GALAPAGOS FINCHES

Scientists have long believed that the 14 species of finches on the Galapagos Islands evolved from a single species of bird that came to the islands one to five million years ago. Recent DNA studies support the conclusion that all of the Galapagos finches evolved from the warbler finch. Different species live on different islands. For example, the medium ground finch and the cactus finch live on one island. The large cactus finch lives on another island. One of the major differences in the finches is in their beak sizes and shapes.

1. What would happen if a breeding pair of finches was placed on an island under ideal conditions with no predators and unlimited food so that all individuals survived? Given enough time
    a. the finch population would stay small because birds only have enough babies to replace themselves.
    b. the finch population would double and then stay relatively the same.
    c. the finch population would increase dramatically.
    d. the finch population would grow slowly and then level off.
2. Finches on the Galapagos Islands require food to eat and water to drink.
    a. When food and water are in short supply, some birds may be unable to obtain what they need to survive.
    b. When food and water are limited, the finches will find other food sources, so there is always enough to eat and drink.

c. When food and water are in short supply, the finches all eat and drink less so that all birds survive.
d. There is always plenty of food and water on the Galapagos Islands to meet the finches' needs.

3. Once a population of finches has lived on a particular island for many years,
   a. the population continues to grow rapidly.
   b. the population remains pretty much the same, with some fluctuations (increases and decreases).
   c. the population dramatically increases and decreases each year.
   d. the population will decrease at a regular rate.
4. In the finch population, what are the main changes that occur gradually over time?
   a. The traits of each finch within a population gradually change.
   b. The amounts of finches having different traits within a population change.
   c. Successful behaviors learned by finches are passed on to their babies.
   d. Mutations occur to meet the needs of the finches as the environment changes.
5. Depending on the beak size and shape, some finches get nectar from flowers, some eat grubs (worms) from bark, some eat small seeds, and some eat large nuts. Which statement best describes the relationships among the finches and the food supply?
   a. Most of the finches on an island cooperate to find food and share what they find.
   b. Many of the finches on an island fight with one another and the physically strongest ones win.
   c. There is more than enough food to meet all the finches' needs so they don't need to compete for food.
   d. Finches compete mainly with closely related finches that eat the same kinds of food, and some may die from lack of food.
6. How did the different beak types **first** appear in the Galapagos Islands?
   a. The changes in the finches' beak size and shape occurred because they needed to be able to eat different kinds of food to survive.

b. Changes in the finches' beaks occurred by chance, and when there was a good match between beak shape and available food, those birds had more babies.

c. The changes in the finches' beaks occurred because the environment caused changes in the finches' genes.

d. The finches' beaks changed a little bit in size and shape with each generation that followed, with some beaks getting larger and some getting smaller.

7. What type of variation in finches is passed to their babies?

   a. Any behaviors that were learned during a finch's lifetime

   b. Only features that were helpful during a finch's lifetime

   c. All features that were determined by their genes

   d. Any features that the environment helped bring about during a finch's lifetime

8. What caused populations of birds having different beak shapes and sizes to become separate and different species that were spread out among the various islands?

   a. The finches were quite numerous and different, and those whose features were best suited to the available food supply on each island reproduced most successfully.

   b. All finches are essentially alike and there are **not** really fourteen different species.

   c. Different foods are available on different islands and for that reason, individual finches on each island gradually developed the beaks they needed.

   d. Different lines of finches developed different beak types because they needed them in order to get the available food.

VENEZUELAN GUPPIES

Guppies are small fish found in streams in Venezuela. Male guppies are brightly colored, with black, red, blue, and reflective spots. Males cannot be too brightly colored or they will be seen and eaten by predators, but if they are too plain, females will choose other males. Natural selection and sexual selection work in opposite directions here. When a guppy population lives in a stream without any predators, the amount of males that are bright and flashy increases in the population. If a few aggressive predators are added to the same stream, the amount of bright-colored males decreases within about five months (3-4 generations). The effects of predators on guppy coloration have been studied in artificial ponds with mild, aggressive, and no predators, and by similar experiments in natural stream environments.

9. A typical natural population of guppies has hundreds of guppies. Which statement best describes the guppies of a single species in an isolated population?
   a. The guppies share all of the same features and are identical to each other.
   b. The guppies share all of the basic features of the species; the minor variations they display don't affect survival.
   c. The guppies are all identical on the inside, but have many differences in appearance.
   d. The guppies share many basic characteristics, but also different in many ways.
10. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Which feature would a biologist consider to be most important in determining which guppies were the "most fit"?
    a. large body size and ability to swim quickly away from predators
    b. excellent ability to compete for food
    c. high number of young that survived to reproductive age
    d. high number of matings with many different females
11. Assuming ideal conditions with a lot of food and space and no predators, what would happen if a pair of guppies were placed in a large pond?
    a. The guppy population would grow slowly, as guppies would have only the number of babies that are needed to restock the population.
    b. The guppy population would grow slowly at first, then grow quickly, and thousands of guppies would fill the pond.
    c. The guppy population would never become very large, because only organisms such as insects and bacteria reproduce in that manner.
    d. The guppy population would continue to grow slowly over time.
12. Once a population of guppies has been established for a number of years in a real (not ideal) pond with other organisms including predators, what will likely happen to the population?

a. The guppy population will stay about the same size.
b. The guppy population will continue to rapidly grow in size.
c. The guppy population will gradually decrease until no more guppies are left.
d. It is impossible to tell because populations do not follow patterns.

13. In guppy populations, what are the main changes that occur slowly over time?
    a. The features of each individual guppy within a population gradually change.
    b. The amounts of guppies having different features within a population change.
    c. Successful behaviors learned by certain guppies are passed on to their babies.
    d. Mutations occur to meet the needs of the guppies as the environment changes.

CANARY ISLAND LIZARDS

The Canary Islands are seven islands just west of Africa. The islands slowly became filled with life: plants, lizards, birds, etc. Three different species of lizards found on the islands are similar to one species found on Africa. Because of this, scientists seem to think that the lizards traveled from Africa to the Canary Islands by floating on tree trunks washed out to sea.

14. Lizards eat different types of insects and plants. Which statement describes the availability of food for lizards on the Canary Islands?
    a. Finding food is not a problem because there is always plenty of food.
    b. Since lizards can eat different types of foods, there is likely to be enough food for all of the lizards at all times.
    c. Lizards can get by on very little food, so the food supply does not matter.
    d. It is likely that sometimes there is enough food, but at other times there is not enough food for all of the lizards.
15. What do you think happens among the lizards of a certain species when the food supply is limited?
    a. The lizards work together to find food and share what they find.
    b. The lizards fight for the available food and the strongest lizards kill the weaker ones.

c. Genetic changes that would allow lizards to eat new food sources are likely to be brought about.

d. The lizards least successful in the competition for food are likely to die of starvation and malnutrition.

16. Populations of lizards are made up of hundreds of individual lizards. Which statement describes how similar they are likely to be to each other?

a. All lizards in the population are likely to be nearly identical.

b. All lizards in the population are identical to each other on the outside, but there are differences in their internal organs such as how they digest food.

c. All lizards in the populations share many similarities, but there are differences in features like body size and claw length.

d. All lizards in the population are completely different and share no features with other lizards.

17. Which statement could describe how features in lizards pass from one generation of lizards to the next generation?

a. Lizards that learn to catch a particular type of insect will pass this new ability to their babies.

b. Lizards that are able to hear, but do not survive any longer because of hearing, will eventually stop passing on the "hearing" feature.

c. Lizards with stronger claws that allow for catching certain insects have babies whose claws gradually get even stronger during their lifetime.

d. Lizards with a particular coloration and pattern are likely to pass the same features on to their babies.

18. Fitness is a term used by biologists to explain the evolutionary success of certain organisms. Below are descriptions of four female lizards. Which lizard might a biologist consider to be the "most fit"?

	Lizard A	Lizard B	Lizard C	Lizard D
Body length	20 cm	12 cm	10 cm	15 cm
Offspring surviving to adulthood	19	28	22	26
Age at death	4 years	5 years	4 years	6 years
Comments	Lizard A is very healthy, strong, and clever	Lizard B has mated with many lizards	Lizard C is dark colored and very quick	Lizard D has the largest territory of all the lizards

a. Lizard A

b. Lizard B

c. Lizard C

d. Lizard D

19. According to the theory of natural selection, where did the differences in body size in the three species of lizards most likely come from?

    a. The lizards needed to change in order to survive, so helpful new features developed.

    b. The lizards wanted to become different in size, so helpful new features slowly appeared in the new population.

    c. Random genetic changes and sexual recombination of genes both created these differences.

    d. The island environment caused genetic changes in the lizards.

20. What could cause one species to change into three species over time?

    a. Groups of lizards came upon different island environments so the lizards needed to become new species with different features in order to survive.

    b. Groups of lizards must have been geographically isolated from other groups and random genetic changes must have been built up in these lizard populations over time.

    c. There may be minor differences, but all lizards are basically alike and all are members of a single species.

d. In order to survive, different groups of lizards needed to adapt to the different islands, and so all organisms in each group gradually evolved to become a new lizard species.

ANSWER KEY

1C, 2A, 3B, 4B, 5D, 6B, 7C, 8A, 9D, 10C, 11B, 12A, 13B, 14D, 15D, 16C, 17D, 18B, 19C, 20B

APPENDIX D

TEACHER INTERVIEW PROTOCOL

PRE-INSTRUCTION/OBSERVATION INTERVIEW

In order to describe and get a sense of each teacher's experience, evolutionary beliefs, and overall orientation to science teaching, the teachers individually participated in a pre-instruction/observation semistructured interview.

Opening Questions: Teaching Experience, Views on Evolution, Goals/Purposes of Instruction

1. How many years have you been teaching and teaching biology, specifically?
2. What is your education background?
3. What is your training with regards to evolutionary biology?
4. What is your approach to teaching evolution?
5. Do you accept evolution?
6. How much time is spent with teaching of evolutionary concepts?
7. What are your purposes and goals for your students over the course of the evolution unit? How did you decide on these purposes and goals?
8. Tell me about your planning process. How do you plan? What is most important in guiding your instructional decisions?
9. What do you perceive as the teacher's role in a typical lesson? What is the students' role?
10. What does an "ideal" science lesson look like to you?

Subject Matter Knowledge

11. Tell me about your previous experiences teaching evolution. Has your approach to this topic changed over time? How?
12. Do you teach evolution independently or do you integrate it into other topics within your biology curriculum?
13. What do you think is important for students to know about evolution? Why do you think that is important?
14. How does evolution relate to other science/mathematical ideas?

Knowledge of Learners

15. Tell me about the students in your classes, in terms of science. Describe your students' attitudes towards science and attitudes towards evolution.
16. What knowledge about your students informs your planning process?
17. What do you think your students will already know about evolution? Why do you think they may already know that?
18. Do you typically assess student learning at the beginning of a lesson? How do you do that?
19. How do you assess students' alternative conceptions?
20. How do you use your knowledge of your students when teaching?

Knowledge of Instructional Strategies

21. Tell me how you plan to help students learn the most important concepts associated with evolution. What are some examples of teaching activities you have used in the past? Which of these did you find most effective? Why?

22. How did you decide upon the instructional strategies you plan to use during your evolution unit?
23. How do you plan to draw out student ideas regarding evolution?
24. How do you think you might change your plans if students do not respond well to your strategies, like questioning?
25. Do you often change your plans "on the fly" in response to student responses?

DAILY INTERVIEW

1. How do you think today went? In what ways was the lesson I observed today different than other periods you taught it? Different from your lesson plan?
2. What knowledge about your students did you use to make instructional decisions?
3. In what ways did your students influence your teaching decisions today?
4. What were the critical science ideas in today's lesson?

POST-INSTRUCTION/OBSERVATION STIMULATED RECALL INTERVIEW

Teachers were asked to view short video segments of their teaching and reflect upon their thinking and teaching during these segments.

Opening Question(s)

1. How do you think this particular lesson went?

Specific Video Questions

I've selected some parts of the instruction I found particularly interesting. I'd like for us to watch these segments together and will then ask you some questions about them.

2. What were you thinking when this was occurring? Tell me more about what was happening when you _________________.

3. What do you think the student(s) was/were thinking? Why do you think the student(s) was/were having difficulty at this particular point?
4. Tell me about that (example/analogy/activity/lab). Why did you decide to use that? Did it help you achieve your overall goals?

Reflection Questions

5. Given the opportunity to sit down with a colleague you trust, what questions would you ask about evolution?
6. How do your lessons on evolution compare to your “ideal” science lessons?
7. Was there anything that occurred during the course of your evolution unit that surprised you?
8. How do you think your teaching is influenced by your colleagues?
9. How do you think you learn science best? How do you think your perception of yourself as a science learner influences your teaching?

CINS Utility

10. Discuss any insights you may have about the CINS pre-test results that were given to you at the beginning of your instructional unit.
11. Please relay any thoughts or insights you may have about the CINS itself.
12. Talk about the CINS’s utility. How might the CINS relate to your teaching practice? Does it relate to your teaching practice?
13. Do you have any recommendations for its future use in a high school classroom?

APPENDIX E

CODING SCHEMES FOR CURRENT STUDY (STUDY #3)

Research Question #1A—Orientation to Science Teaching and Lesson Alignment

	Coding Construct	Emergent Theme	Occurrence of Emergent Theme	Criteria for Lesson Alignment
Teacher A	Teacher role	provide information	Yes	Majority of lessons (≥5) depict teacher presenting and explaining evolutionary concepts to students, leading instructional activities with questioning, planning methodology of simulations and experiments
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥5) or entirely in less than half (1-4) of lessons
			No	Minimal occurrence of teacher providing information across majority (≥5) of lessons
	Student role	"active" receiver of knowledge	Yes	Majority of lessons (≥5) depict students listening/taking notes during teacher lectures and presentations, asking higher-order (e.g. Why? How?) questions about subject matter, and initiating investigation of subject matter
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥5) or entirely in less than half (1-4) of lessons
			No	Minimal occurrence of criteria described above across majority (≥5) of lessons
	Ideal science lesson	follow specific sequence: engagement activity, teacher-led lecture, student-led	Yes	Majority of lessons (≥5) follow a specific sequence: engagement activity, teacher-led lecture, and student-led investigation
			Somewhat	Same criteria as above, but two out of three aspects occurring

		investigation		sporadically across majority (≥5)
			No	No occurrence of criteria described above across majority (≥5) of lessons

	Coding Construct	Emergent Theme	Occurrence of Emergent Theme	Criteria for Lesson Alignment
Teacher B	Teacher role	make scientific concepts less abstract	Yes	Majority of interactions (≥60%) depict teacher using various strategies, including videos, visual representations, and “hands-on” activities to help students further understand evolutionary concepts
			Somewhat	Same criteria as above, but any use of above strategies occurs sporadically (30%-59%) across interactions
			No	Minimal occurrence (≤ 29%) of criteria described above across interactions
	Student role	“active” receiver and constructor of knowledge	Yes	Majority of lessons (≥6) depict students listening/taking notes during teacher lectures and presentations, asking higher-order (e.g. Why? How?) questions about subject matter, and initiating investigation of subject matter
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6)
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
	Ideal science lesson	follow specific sequence: teacher-led lecture, student-led investigation, closure with short assessment	Yes	Majority of lessons (≥6) follow a specific sequence: teacher-led lecture, student-led investigation, and closure with short written/verbal assessment
			Somewhat	Same criteria as above, but two out of three aspects occurring sporadically across majority (≥6)

			No	No occurrence of criteria described above across majority (≥6) of lessons

	Coding Construct	Emergent Theme	Occurrence of Emergent Theme	Criteria for Lesson Alignment
Teacher C	Teacher role	"mentally prepare" students for learning	Yes	Majority of lessons (≥6) depict teacher using various instructional activities (e.g., videos, writing prompts, individual/group assignments) to introduce different evolutionary concepts **and** scaffolds activities for conceptual understanding through thoughtful presentation of student ideas
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
	Student role	constructor of knowledge	Yes	Majority of lessons (≥6) depict students actively engaged in exploration of evolutionary concepts in order to determine and interpret scientific explanations for themselves
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
	Ideal science lesson	hands-on activities and scientific discourse among students	Yes	Majority of lessons (≥6) depict students actively engaged in hands-on activity or scientific investigation **and** discussing evolutionary concepts with each other
			Somewhat	Same criteria as above, but one out two aspects occurring sporadically across majority (≥6)
				No occurrence of criteria

				described above across majority (≥6) of lessons

	Coding Construct	Emergent Theme	Occurrence of Emergent Theme	Criteria for Lesson Alignment
Teacher D	Teacher role	balance between providing information and having students do intellectual work	Yes	Majority of lessons (≥6) depict teacher explaining evolutionary concepts to students through various presentations, videos, and visual representations, and students determining and interpreting overall themes and patterns from various activities and assignments
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
	Student role	"active" receiver and constructor of knowledge	Yes	Majority of lessons (≥6) depict students listening/taking notes during teacher lectures and presentations, asking higher-order (e.g. Why? How?) questions about subject matter, and initiating investigation of subject matter
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
	Ideal science lesson	follow specific sequence: review of previous lesson's main ideas, engagement activity, teacher-led lecture, and	Yes	Majority of lessons (≥6) follow a specific sequence: review of previous lesson's main ideas, engagement activity, teacher-led lecture, and student-led investigation
			Somewhat	Same criteria as above, but two out of four aspects occurring sporadically across majority (≥6) of lessons

		student-led investigation	No	No occurrence of criteria described above across majority (≥6) of lessons

<u>Research Question #1B—Orientation to Evolutionary Theory and Lesson Alignment</u>

	Coding Construct	Emergent Theme	Occurrence of Emergent Theme	Criteria for Lesson Alignment
Teacher A	Complete acceptance or ambivalence	Complete acceptance	Yes	Majority of lessons (≥5) depict teacher and students engaging in evolutionary concepts as scientific facts with minimal references to religion or alternate ideas
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥5) or entirely in less than half (1-4) of lessons
			No	Minimal occurrence of criteria described above across majority (≥5) of lessons
	Purposes and goals of instructional unit on evolution	Evolution is not "just a theory" and is supported with scientific evidence	Yes	Majority of lessons (≥5) emphasize evolution as a scientific fact with supporting evidence through incorporation in lesson topics, teacher-student discourse, and instructional activities
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥5) or entirely in less than half (1-4) of lessons
			No	Minimal occurrence of criteria described above across majority (≥5) of lessons
		Emphasis on populations evolving, not individuals	Yes	Majority of lessons (≥5) emphasize concept that populations evolve, and not individuals through incorporation in lesson topics, teacher-student discourse, and instructional activities

			Somewhat	Same criteria as above, but occurring sporadically across majority (≥5) or entirely in less than half (1-4) of lessons
			No	Minimal occurrence of criteria described above across majority (≥5) of lessons
		Emphasis on evolution taking time	Yes	Majority of lessons (≥5) emphasize concept that evolution takes a substantial long time (millions of years) to occur through incorporation in lesson topics, teacher-student discourse, and instructional activities
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥5) or entirely in less than half (1-4) of lessons
			No	Minimal occurrence of criteria described above across majority (≥5) of lessons
		Compartmentalization of concepts	Yes	Majority of lessons (≥6) emphasize “separateness” of evolutionary concepts. Concepts are initially presented with minimal connection to each other, then synthesized with instructional activity/assignment
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥5) or entirely in less than half (1-4) of lessons
			No	Minimal occurrence of criteria described above across majority (≥5) of lessons

	Coding Construct	**Emergent Theme**	**Occurrence of Emergent Theme**	**Criteria for Lesson Alignment**
Teacher B	Complete acceptance or ambivalence	Complete acceptance	Yes	Majority of lessons (≥6) depict teacher and students engaging in evolutionary concepts as scientific facts with minimal references to religion or alternate ideas

			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
	Purposes and goals of instructional unit on evolution	Emphasis on organisms evolving from a common ancestor	Yes	Majority of lessons (≥6) emphasize concept that organisms evolve from a common ancestor through incorporation in lesson topics, teacher-student discourse, and instructional activities
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons

	Coding Construct	**Emergent Theme**	**Occurrence of Emergent Theme**	**Criteria for Lesson Alignment**
Teacher D	Complete acceptance or ambivalence	Complete acceptance	Yes	Majority of lessons (≥6) depict teacher and students engaging in evolutionary concepts as scientific facts with minimal references to religion or alternate ideas
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
	Purposes and goals of instructional unit on evolution	Evolution is not "just a theory" and is supported with scientific evidence	Yes	Majority of lessons (≥6) emphasize evolution as a scientific fact with supporting evidence through incorporation in lesson topics, teacher-student discourse, and instructional activities
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons

			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
		Emphasis on organisms evolving from a common ancestor	Yes	Majority of lessons (≥6) emphasize concept that organisms evolve from a common ancestor through incorporation in lesson topics, teacher-student discourse, and instructional activities
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
		Emphasis on key vocabulary	Yes	Majority of lessons (≥6) emphasize key vocabulary for students to learn through incorporation in teacher-student discourse and instructional activities/assignments
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons

	Coding Construct	**Emergent Theme**	**Occurrence of Emergent Theme**	**Criteria for Lesson Alignment**
Teacher C	Complete acceptance or ambivalence	Ambivalent	Yes	Majority of lessons (≥6) depict teacher and students engaging in evolutionary concepts as scientific facts that need to be questioned; includes references to religion or alternate ideas
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons

	Purposes and goals of instructional unit on evolution	Emphasis on evolution taking time	Yes	Majority of lessons (≥6) emphasize concept that evolution takes a substantial long time (millions of years) to occur through incorporation in lesson topics, teacher-student discourse, and instructional activities
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Minimal occurrence of criteria described above across majority (≥6) of lessons
		De-emphasize "human-centric" view of evolution	Yes	Majority of lessons (≥6) emphasize that evolution occurs in other organisms, not just humans evolve, through incorporation in lesson topics, teacher-student discourse, and instructional activities/assignments
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
		Retain openness to alternate ideas of evolution	Yes	Majority of lessons (≥6) emphasize for students to remain open to alternate ideas that might explain evolution, even if they are nonscientific. Openness to ideas is reflected in instructional activities/assignments and teacher-student discourse.
			Somewhat	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons
			No	Same criteria as above, but occurring sporadically across majority (≥6) or entirely in less than half (1-5) of lessons

Research Question #2—Teacher-Student Interactions That Elicit Alternative Conceptions

Coding Category	Possible Codes	Criteria	Example
Teacher-to-Student Questioning	Alternative Conceptions and Prior Knowledge	Teacher probes for student ideas/predictions on a topic/concept before topic/concept is formally introduced, explored, presented, or further investigated	Teacher D: What came to mind when you thought of evolution? What does it mean to you? What comes to mind? S1: We came from apes. S2: We went from a small, tiny ape and eventually turned into man. Teacher D: From ape to man...OK. Anybody else have any other ideas? (Class lesson, Day 1, 3/19/12)
	Recall	Teacher probes students for recall of facts, definitions, results, or information after a topic/concept has been formally introduced, explored, presented, or further investigated	(two interactions in example) *Teacher A begins class by having students answer review questions from the notes they have been taking since the previous day.* Interaction #1 Teacher A: And where else did [Darwin] go? SS: Around the world. Teacher A: Around the world. Interaction #2 Teacher A: And how long did that trip take? SS: Five years. Teacher A: Five years. (Class lesson, Day 2, 3/21/12)
	Comprehension	Teacher probes students for understanding/grasping meaning/interpretation of concepts, results, data, or information	*Teacher C pauses the video.* Teacher C: And what you guys can see on that very first picture...is what? S1: That at first... S2: You see birds only eating the green beetles. Teacher C: Only green and then what happens? S1: Then the orange... S3: So now that changes their environment. S4: All that's left are yellow [orange]. Teacher C: So all of them are just yellow left? And look at the word they use at the very top part. What are they

			giving you guys in a nutshell? S3: Natural selection. Teacher C: Natural selection…and basically it's saying the fittest organism will be able to survive and pass on their genes...(Class lesson, Day 5, 4/3/12)
	Confirmation	Teacher gets students (usually entire class) to confirm trends, results, or facts through use of rhetorical/leading questioning	Teacher B: So the traits are what's being represented by those [poker] chips. If we take a large population...which is what genetic drift does, right? It takes a large population and only a few of that population gets separated...we don't have all the population's traits to mix with anymore, right? If we got stranded on an island and there were like ten of us stranded on that island, and there's no way for us to have gotten out 'cause nobody's going to find us, could we still reproduce? SS: Yes. Teacher B: Yes. I never said we were all girls or all boys...then we'd be in trouble...(Class lesson, Day 9, 4/5/12)

Research Question #4—Classroom Interactions with CINS Concepts

Coding Category	Possible Codes	Criteria (from Anderson et al., 2002)
Interaction with CINS concepts	Differential Survival	Interaction involves talk about biological fitness in that those individuals whose surviving characteristics fit them best to their environment are likely to leave more offspring than less fit individuals
	Variation within a Population	Interaction involves talk about how individuals of a population vary extensively in their characteristics
	Inheritable Variation	Interaction involves talk about traits being inherited from parent to offspring
	Limited Survival	Interaction involves talk about

		how production of more individuals than the environment can support leads to a struggle for existence among individuals of a population
	Natural Resources	Interaction involves talk about natural resources necessary for organisms to live are in limited supply at any given time
	Change in a Population	Interaction involves talk about how: 1) the unequal ability of individuals to survive and reproduce will lead to gradual change in a population, as opposed to individual members, and 2) learned behaviors are not inherited
	Origin of Variation	Interaction involves talk about how random mutations and sexual reproduction produce variations and while many are harmful or of no consequence, a few are beneficial in some environments
	Origin of Species	Interaction involves talk about how an isolated population may change so much over time that it becomes a new species
	Biotic Potential	Interaction involves talk about species having great potential fertility in that their population size would increase exponentially if all individuals that are born would again reproduce successfully
	Population Stability	Interaction involves talk about populations being mostly stable in size except for seasonal fluctuations

Coding Example:

Example from Teacher A's class lesson on 3/20/12 showing presence of four different CINS concepts within one interaction.

Teacher A: **So over time...say 10...15 generations later...you come back and you look at this population of birds [change in a population (CP)** living on the island, **what do their beaks look like?**

SS: Big.

Teacher A: Big...why? [Variation in a Population (VP)]

S1: Because of [Student L]...

Teacher A: ...**So everybody else that had larger beaks is surviving. [Differential Survival (DS)] So their genes are going forward and the ones that had genes [Inheritable Variation (IV)] for smaller beaks [VP]...not going anywhere [IV].**

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