ABSTRACT

GREEN, KATHRYN ELLEN. Crossing Cultural Borders: How a Pedagogical Intervention Affected Community College Biology Students’ Learning about Evolution. (Under the direction of Dr. Cesar Delgado).

Evolution is an essential underlying concept in biology. Previous research demonstrates that many obstacles exist that prevent successful teaching and learning about evolution. This research used the theoretical framework of cultural border crossing and its underlying cognitive explanation, collateral learning, to design an intervention for community college students in an introductory biology class for non-science majors. Cultural border crossing posits that learners might encounter extensive differences between their home cultures and the culture of the science classroom and may need assistance in navigating the crossing of these cultural borders. The intervention included four mini-lessons focused on sources of knowledge that were designed to alleviate tension for students who were crossing cultural borders between scientific and religious worldviews while learning about evolution as the best scientific theory to account for the diversity of life on Earth.

Quantitative and qualitative data were collected to determine how this intervention affected students’ understanding and acceptance of evolution. Results showed there was a small positive effect on the students’ understanding and acceptance. Qualitative results indicated that the students with the largest gaps between the two cultures were appreciated the intervention strategy that valued their religious sources of knowledge. Five themes emerged from the analysis: others as influencers of cultural border crossing and collateral learning, The Road to Homo Sapiens as an obstacle, affective reactions related to evolution, a new category of cultural border crossers needed for the framework, and perspectives on sources of knowledge. Results and suggested that more research should be done on how
students’ cultures influence their learning about evolution and how educators can best facilitate learning among students with various cultural beliefs about the diversity of life on Earth. This research also implies that professional development for educators related to The Road to Homo Sapiens and teleological thinking would also lead to an increase in understanding and acceptance of evolution by all students. We live in an era in which understanding scientific concepts and principles is vital and this research illuminates further work that can be done to ensure evolution, an essential underpinning of biology, is fully understood by learners of all types.
Crossing Cultural Borders: How a Pedagogical Intervention Affected Community College Biology Students’ Learning about Evolution

by
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DEDICATION

To my parents, Bonnie and Kinney, who taught me the value of an education from birth, played school with me throughout my childhood, and showed me what hard work looks like.

And to Tom Breuckman, my first principal, who encouraged me to be the best science teacher I could be. I could not have accomplished this without all my amazing experiences with teachers, students, and parents at da Vinci Arts Middle School.
Kathryn Ellen Green was born in Danville, Virginia, on Parents’ Weekend at her dad’s school in October 1973. She attended James Madison University where she majored in Anthropology. Afterward, she earned a Masters degree in Anthropology at University of Oregon, focusing on Pacific Islands archaeology. After completing her teaching certification at University of Oregon, Katie taught middle school science for twelve years in Portland, Oregon and Raleigh, North Carolina. Katie enrolled in the PhD program in the fall of 2015, amazed that her dream of further education was finally being realized. She is very excited about her future as a science education researcher.
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CHAPTER 1

“The Great Temptation of educators is to teach students nothing but the truth—as they understand it, of course.” ~Warren Nord

What is the truth about evolution? Is the truth taught by teachers the same as the truth learned by students? In other words, is everyone’s truth the same? And is there only one true truth? This dissertation examines how community college biology students manage tensions that arise between their religious and scientific worldviews when learning about evolution. It also measures whether and how a carefully-designed intervention created based on the cultural border crossing and collateral learning frameworks affects students’ understanding and acceptance of evolution. The results of this dissertation are valuable to science education because evolution is a concept to which there is much resistance and science education has failed to solve this issue, and because research on evolution education on community college students (who are representative of the general public) is scant in the literature. This chapter will provide an overview of the problem this research examines, the purpose of the research, the methods used, and additional rationale and significance behind this research.

Problem Statement

Evolution, the scientific theory that life has changed over time through descent with modification, is the basis of all biological sciences and is a key component of scientific literacy. As Theodosius Dobzhansky famously said, “Nothing in biology makes sense except in the light of evolution.” (1973, p. 125). Scientists agree that the Earth was populated with
various species through the process of evolution. However, evolution is rejected by many people in the American public. For example, many Americans believe humans were not created through the process of evolution. A recent Gallup poll shows that 38% of Americans believe that God created humans in their current form, thereby denying evolution as a universal biological process that applies to humans as well as other organisms. Another 38% chose the option that man developed with the guidance of God (theistic evolution), and 19% chose the option that man developed but God had no part in the process (non-theistic evolution) (Swift, 2017). As one can see from this recent poll, religion and science often collide when people consider evolution. This lack of agreement between scientists and the public about evolution led the editor of a biology education journal to conclude “it [evolution understanding and acceptance] is by far the biggest failure of science education from top to bottom” (Christensen, 1998, p. D3). Twenty years after this comment was made, evolution continues to be a challenge for both teachers and learners (Pobiner, 2016). This dissertation provides an overview of obstacles to teaching and learning about evolution, and the research focuses specifically on how using the cultural border crossing theoretical framework during an evolution unit might lead to greater knowledge and acceptance of evolution by students with various religious/cultural and scientific worldviews.

Understanding evolution is important for not only the scientific community, but for the public as well. First, in the economic arena, the world needs to produce scientists who can create technological and scientific advances (Sargent, 2017). Several newer scientific areas such as genomics are based on evolutionary concepts. Second, the public needs to understand the evolutionary aspects of daily life so they can make responsible choices about
issues such as genetically modified organisms, antibiotics, and vaccines. Third, in a cultural sense, the public needs to be well-educated on scientific issues such as evolution in order to appreciate the world around us and how it impacts our lives (Smith, 2010). In addition, as science becomes more politicized and mistrust in scientists increases, it is important to examine the constructs related to acceptance of evolution as a valid scientific theory (Nadelson & Hardy, 2015). Otherwise, “those distrustful of science are being left behind, not just in understanding how the world works, but in the work that elevates world economies” (Rissler, Duncan, & Caruso, 2014).

In the 1980s and 1990s, much science education research focused on the process of identifying students’ misconceptions (more currently termed “alternative conceptions”) and subsequently guiding students through the process of conceptual change. According to Strike and colleagues, a new concept could be accepted if the original concept was dissatisfactory to the learner and the new concept was intelligible, fruitful, and plausible (Posner, Strike, Hewson, & Gertzog, 1982). While Posner and colleagues discussed the assimilation and accommodation of new concepts, the conceptual change model emphasized the substitution or replacement of one conceptual schema with another, rather than acknowledging the modification of conceptual schema that frequently occurs (diSessa, 2006). Many studies identified the alternative conceptions, but little work examined the early roots of a concept in general or how multiple concepts could be combined to create a coherent whole (diSessa, 2006). While discovering students’ alternative conceptions can be enlightening, focusing on what students know that is “wrong” and telling them the “right” thing to believe instead can lead to what has been termed “cognitive apartheid” (Cobern, 1994). Cobern defined cognitive apartheid as the process through which students create
walls to keep out concepts that do not align with their typical ways of thinking. This process leads to a student building “a compartment for scientific knowledge from which it can be retrieved on special occasions, such as a school exam” (Cobern, 1994, p. 9) but is not used in the everyday life of the student. Learning that includes cognitive apartheid does not constitute true learning but is instead more akin to memorization. Teaching students that their “wrong” ways of thinking should be replaced with the “right” ways of thinking does not consider students’ cultures with an aim to encourage equity or value diversity.

Previous research suggests that students with worldviews that do not allow for evolution acceptance are not likely to effectively learn about evolution unless the issues surrounding the conflict is addressed (Pobiner, 2016). A promising new approach to cross the chasm between students’ previous (often cultural or religious) knowledge and scientific knowledge is through facilitating cultural border crossings so that students can surmount obstacles to learning that might be related to a lack of scientific worldview. Recent research has focused on how students move between their everyday cultural worlds and the world of school science, termed cultural border crossings, and how students deal with cognitive conflicts between those worlds (Aikenhead & Jegede, 1999). While the cultural border crossing framework was originally developed with the context of non-Western cultures, this dissertation applies it in a new context. A second important concept used in this study is that of collateral learning, which Jegede defined as “an accommodative mechanism for the conceptual resolution of potentially conflicting tenets within a person’s cognitive structure” (Jegede, 1995, p. 117). This dissertation research focuses on cultural border crossing, the process through which learners may move “between their everyday life-world and the world of school science” (Jegede & Aikenhead, 1999, p. 45) and collateral learning, the cognitive
explanation behind how learners react to conflicting worldviews. Four types of cultural border crossing and four types of collateral learning are described in Chapter Two.

**Statement of Purpose**

The purpose of this research is to improve students’ understanding and acceptance of evolution. Conflicts regarding the teaching of evolution have led to a need for new approaches to teaching evolution that can help students develop new understandings of evolution. An intervention using the cultural border crossing and collateral learning theoretical frameworks was designed and subsequently enacted by a community college biology professor who aimed to facilitate border crossing between culturally-based and scientific worlds. Class discussions focused on the relationship between science and religion, types of epistemological sources (religion, science, law, etc.) and how various sources of knowledge help answer different types of questions. The intervention was designed to help students develop more complex understandings of the epistemological positions and ways of knowing when navigating conflicting worldviews while learning about evolution and to increase understanding and acceptance of evolution. The approach used in this research is based on the assumption that facilitating students’ understandings about scientific ideas regarding evolution is likely to result in better acceptance and understanding of evolution. The words “acceptance” and “understanding” were specifically chosen because the two are not mutually exclusive and “acceptance” is related to the scientific evaluation of evolution as the best explanation for the diversity of life on Earth based on scientific evidence (Ingram & Nelson, 2006). For students who already hold views which are compatible with science, this intervention will result in confirming their scientific worldviews and not in adopting a second worldview.
This intervention attempts to teach students evolutionary concepts in ways that promote evolution understanding. As advocated by the National Center for Science Education, “a science teacher’s professional responsibility is to teach science” (National Center for Science Education, n.d.). Other science education organizations also have positions on the teaching of evolution in the classroom. The National Science Teachers Association, while focusing on K-12 education, declared that “science teachers should not advocate any religious interpretations of the natural world and should be nonjudgmental about the personal beliefs of students” (“NSTA Position Statement,” 2013). During this research, the biology instructor was careful to be nonjudgmental about students’ religious views while also not presenting religion as a valid substitute for scientific evidence to support evolution. The position statement of the National Association of Biology Teachers (NABT) is aligned with those of the NCSE and NSTA, and explains, “Science teachers must reject calls to account for the diversity of life…by invoking non-naturalistic or supernatural notions, whether called ‘creation science,’ ‘scientific creationism,’ ‘intelligent design theory,’ or similar designations (NABT Board of Directors, 2011). The NABT also stresses, “evolution should not be misrepresented as ‘controversial,’ or in need of ‘critical analysis’ or special attention for any supposed ‘strength or weakness’ any more than other scientific ideas are” (NABT Board of Directors, 2011). This research therefore explores models of learning in which a scientific worldview can be adopted if not already possessed by a student.

This research will contribute to filling the gap in the literature on evolution teaching and learning by focusing on the following research questions:
RQ1) How do community college biology students’ understanding and acceptance of evolution change over time after a pedagogical intervention focused on the cultural border crossing model?

RQ2) How do community college biology students navigate border crossings that might be necessary due to conflicting religious and scientific beliefs using some form of collateral learning?

Overview of Methods

This dissertation research is a sequential explanatory mixed-methods study (Creswell, 2003) conducted in two introductory biology classes for non-science majors at a local community college in the Southeastern US.

Research Setting and Sample

This research was completed at a local community college that enrolls over 74,000 adults every year and has multiple campuses along with online options for education. Community college students were chosen as research participants for several reasons. First, community colleges represent the public in that they contain large numbers of non-traditional students from many ethnic/racial and socioeconomic backgrounds with significant life experiences which form existing knowledge structures (Duda, 2008). In this sense, the sample more representatively mirrors the general public.

Second, although community colleges are an increasingly popular route to higher education, educational research on community colleges has not increased proportionately, so community college students are under researched (Terenzini & Pascarella, 1998). More research is needed to understand the typical community college student’s knowledge and
understanding of evolution as well as the religious and cultural worldviews they bring to the
classroom.

An anthropologist often cited in educational literature is Michael Kearney, who
defines worldview as “a set of images and assumptions about the world” (1984, p. 10). The
lens Kearney chooses to examine worldview through is one of historical materialism, which
focuses on the material and social origins of knowledge. In other words, students’
worldviews emanate from their social and material experiences in their worlds. As Kearney
(1984, p. 41) explains, “a world view comprises images of Self and all that is recognized as
not-Self, plus ideas about relationships between them, as well as other ideas…”
(capitalizations in original). Cobern applied worldview to science education and shared an
equation he created to demonstrate that world view is the total of all cultural components a
person possesses:

\[ n_1 \text{Religion} + n_2 \text{Gender} + \ldots + n_{10} \text{Ethnicity} + n_{11} \text{Scientific}=\text{Worldview} \] (1996, p. 588)

This study will add to the research base while developing and assessing a promising
instructional approach that allows students to keep their cultural beliefs that may be alternate
conceptions while simultaneously developing accurate scientific conceptions of evolution
rather than asking them to discard the beliefs through conceptual change.

Third, my own experience teaching community college anthropology classes, which
include a focus on evolution, inspired me to learn more about community college students’
worldviews. More specific information about the research setting and sample will be
described in Chapter Three.
Quantitative Data Collection

This research uses two validated instruments to measure students’ knowledge about and acceptance of evolution. The Concept Inventory of Natural Selection (CINS) measures understanding of evolution and natural selection (Anderson, Fisher, & Norman, 2002) and was first published in *Journal of Research in Science Teaching* in 2002. It has been cited hundreds of times and is widely used in evolution education research (Andrews, Leonard, Colgrove, & Kalinowski, 2011; Keleman & Rosset, 2009; Nehm & Schonfeld, 2008). Acceptance of evolution was determined using the Measurement of Acceptance of the Theory of Evolution (MATE). This instrument was developed by Rutledge and Warden (1999) and published in *School Science and Mathematics*. The MATE has also been used frequently and reliably in evolution education research (e.g., Borgerding, Deniz, & Anderson, 2017; Everhart & Hameed, 2013; Kim & Nehm, 2011; Moore, Cotner & Bates, 2009). These instruments are discussed more thoroughly in Chapter Three.

Qualitative Data Collection

Qualitative data was collected through assessments given during the evolution unit, including an evolution autobiography, a school board scenario assignment that tasked students with applying their evolution knowledge and beliefs to a real-world issue, and a card sort about sources of knowledge. Using a sequential explanatory mixed methods design, qualitative data was collected through semi-structured interviews held before and after the evolution unit with six students selected using purposive sampling. In the third chapter, all data are thoroughly discussed along with data analyses processes.
Rationale and Significance

An examination of the literature on the topic of evolution shows that evolution is often misunderstood—by teachers, students, and sometimes even scientists. For instance, one study showed that 98% of undergraduate biology students who were non-science majors agreed with at least one of six alternative conception statements regarding evolution while 93% of biology majors agreed with at least one of the same sets of alternative conception statements (Coley & Tanner, 2015). Another study demonstrated that a common alternative conception among undergraduate students is that evolution means humans descended from monkeys (Robbins & Roy, 2007). Several decades of educational research from the misconceptions/alternative conceptions perspective have not yielded positive outcomes, so it is imperative to recognize that students’ belief systems are robust, and we need to explore ways of building scientific knowledge that emphasizes the coexistence of beliefs rather than the replacement of them.

Religious beliefs often play a part in students’ resistance to learning about evolution. Recent research at three different colleges demonstrated that college students sometimes believe evolution cannot be correct because it contradicts the Biblical story of creation and found that almost all students came to class identifying as either a creationist or an evolutionist (Kelly, Stoddard, & Allard, 2016). A study of Mormon students found that they had incorrect understandings of the Church of the Latter-Day Saints’ published neutral stance on evolution, believing that Mormonism forbade the acceptance of evolution as the explanation for the diversity of life on Earth, and these misunderstandings served as an obstacle to evolution understanding and acceptance among the students (Manwaring, Jensen, Gill, & Bybee, 2015). While many research studies like these collected and analyzed
quantitative data on evolution understanding and acceptance, few have explored the intrinsic and extrinsic factors that lead to understanding and acceptance of evolution (Glaze & Goldston, 2015).

Religion and science are sometimes thought to answer the same questions, such as “How did I get here?” However, they answer different questions. Scientific methodology is incapable of finding out whether God plays a role in the universe and religion is unable to provide the age of the Earth (Skehan, 2000). Therefore, students may need to cross borders between their religious beliefs and science multiple times in order to accept evolution as a valid scientific theory. The terms “belief” and “acceptance” are sometimes used interchangeably but have very different meanings. In this research, the term “belief” will not be used to refer to evolution and other scientific concepts, but instead the term “acceptance” will be used to refer to the result of an examination of the validity, persuasiveness, plausibility, and empirical support of an idea (Nadelson and Southerland, 2012).

This research is beneficial to educators who teach about evolution. Since evolution educators continue to confront obstacles on a global scale (Deniz & Borgerding, 2018), this research provides data concerning how one of the biggest obstacles, the clash between cultural/religious beliefs and scientific understanding, can be remediated using an intervention.

**Frameworks**

In a constructivist philosophy, research starts at the individual level and then searches for patterns that can lead to even broader understandings (Creswell & Plano Clark, 2011). Constructivism posits that students enter the classroom with pre-existing sets of ideas based on their interactions with others, and some of these ideas may be constructed firmly because
they are entrenched in an individual’s identity and are therefore difficult to disarticulate. The qualitative nature of this intervention will assist participants in reflecting on how they constructed their own worldview about evolution and thinking about how this worldview may or may not affect a worldview they also hold about science. Each student may have their own constructed reality, and they may not share their own reality with others in the class. Since “mixed methods research is…an approach to knowledge…that attempts to consider multiple viewpoints, perspectives, positions, and standpoints” (Johnson, Onwuegbuzie, & Turner, 2007, p. 113), it is a particularly appropriate research methodology for this study.

The theoretical framework of cultural border crossing used in this study aligns with constructivism in that it acknowledges that students may encounter multiple realities that influence the meanings they create. This model was first described by Aikenhead (1996) who discussed how students experience cultural shifts when they move from the world of family and friends into the subculture of science classrooms. Later, Aikenhead and Jegede (1999) expanded on this idea by discussing how successfully learning science requires the adoption of the culture of science, which may be vastly different from the culture in which a student was raised. The authors stated that “the transition from a student’s life-world into a science classroom is a cross-cultural experience for most students” (Aikenhead & Jegede, 1999, p. 271). When the border is wide, and the two sides contain different types of rules and ideas, “it is little wonder that border crossing into school science is not smooth for most students” (Aikenhead & Jegede, 1999, p. 275). It is important to remember that in the cultural border crossings framework both sides of the border are valid, and students are not expected to make a one-way trip across the border, discarding all their previous beliefs like useless, left-behind
possessions. Instead, students retain their previous beliefs, and also understand a new worldview. See Figure 1 for a visual representation of crossing cultural borders.

Figure 1. Theoretical framework of cultural border crossing (Aikenhead, 1996). Students’ home culture, in this case indicating that evolution is a myth, is on one side while the teacher lecturing to students is on the other. A large gulf exists between these two cultures and a bridge exists to cross between cultures.

The mechanism that allows students to keep both the beliefs important to their community contexts and the identities that are interwoven in their home cultures and accept scientific evidence as valid through border crossing is an example of collateral learning, which can be broken down into four types (Aikenhead & Jegede, 1999). Lenses of cultural border crossing and collateral learning were used as data about students’ acceptance of evolution was collected and analyzed. These lenses are further discussed in Chapter Two.
The collateral learning mechanism that allows learners to hold two conceptual schemata as valid, whether simultaneously, in parallel, or through some sort of amalgamation (Jegede, 1995), is a different perspective than many traditional learning theories that learners only hold one conceptual explanation of a phenomenon. Jegede (1995) posited this mechanism related to non-Western students whose indigenous culture did not align well with the culture of the science classroom, and it is plausible that collateral learning can also occur when Western students with deep religious beliefs enter the contrasting culture of a science classroom. When studying evolution, religious students are often confronted with scientific explanations that seem to conflict with their extant religious beliefs, and students do not always discard one of the conflicting ideas. For example, the recent Gallup poll (Swift, 2017) found 38% of Americans embrace theistic evolution, the belief that humans developed with the guidance of God. Theistic evolution is difficult to explain in a conceptual change model, which relies on Piagetian accommodation, because neither schools nor churches are likely teaching theistic evolution. Piaget’s (Piaget & Cook, 1952) process of assimilation - incorporating new information into an existing mental schema, with a small amount of restructuring of the schema – could allow for belief in theistic evolution. However, science education research has found students who voice belief in creationism within their religious communities and understanding and acceptance of evolution in the science classroom (Hanley, Bennett, & Ratcliffe, 2014). Piagetian theory does not allow for the acceptance of two contradictory schemata. In fact, Piagetian theory poses that accommodation is the result of disequilibrium caused by information that does not fit well with an already existing schema. Holding two ideas that explain the same phenomenon, but are not easily aligned, transcends Piagetian theory. Exploring how students hold two competing schemata to
explain the diversity of life on Earth through ideas such as theistic evolution allows me to test a novel framework (cultural border crossing) to explain the structure of knowledge.

**Organization of Dissertation**

This dissertation is organized in the traditional five-chapter method (Bloomberg & Volpe, 2018). The first chapter is the introduction, and includes the problem statement, research questions, and an overview of the methodology. Next, the second chapter introduces the relevant literature related to the research questions. It also includes the theoretical framework that guides this research. Chapter Three contains the rationale for the mixed methods research approach chosen as well as information about the research setting, sample, data sources, data collection methods, data analysis methods, and measures taken to ensure validity and reliability while lessening possible limitations. Chapter Four presents the findings of this research beginning with the quantitative data to answer RQ1 and followed by the qualitative data to answer RQ2. It also synthesizes the results and connects them to previous research from the literature review. Chapter Five summarizes and presents highlights found as a result of the analysis. It also presents conclusions, implications, and assertions with respect to findings. After these five chapters, a list of references will be presented. Finally, the appendices contain the research instruments used, sample interview transcripts, interview protocols and so on.
CHAPTER 2

Literature Review

This chapter contains a review of the relevant literature for this study. First, evolution is described. Second, relevant previous research on teaching and learning evolution is examined and critiqued. Third, how epistemological sources affect belief systems is discussed and what happens when information from different sources of knowledge collides is examined. Fourth, previous research on assessing understanding and acceptance of evolution is presented. Finally, the cultural border crossing and collateral learning frameworks are explored as possible support for evolution learners. This literature review provides an overview of evolution education and highlights the gap in the literature that will be filled by this research.

Evolution in Context

Evolution is an underlying and unifying theme in biology. However, the term evolution did not originate in the biological sciences. The word evolution first appeared in English in 1647 and was used to describe the change from simpler to more complex. It was then used in 1670 to describe how changes occurred as insects matured over time. Darwin did not use the term until his 1873 edition of his famous book *On the Origin of Species by Means of Natural Selection* (Ayala, 2007). Although the word evolution is used in non-biological ways in our everyday language, the biological definition of evolution is that species have undergone descent through modification from common ancestors (Ayala, 2007). In science, the term evolution explains the process through which changes in heritable traits are passed down to offspring accounting for the diversity of life on Earth.
Prior Interventions in Evolution Education

Previous research studies have focused on pedagogical strategies teachers employed that lessen the effects of conflict between different sources of knowledge when studying how diversity of life on Earth arose. Several of these studies are described in this section.

A successful pedagogical strategy is aware of the challenges that exist when various worldviews collide and recognizes that if the learner’s existing knowledge is coherent and deeply intertwined with other knowledge they hold, the likelihood of change decreases. Change is also less likely if the learner is deeply committed to their existing point of view, even if it is not a well-connected set of ideas. Other factors that play a role in change are: interest, emotional involvement, having a stake in the outcome of a dispute between two points of view, and social context (Sinatra, Brem, & Evans, 2008). A desire to understand more about the factors that influence changes in learners’ points of view led to the collection of qualitative data as part of this research.

Research done by Abraham and colleagues attempted to confront and replace community college biology students’ alternate conceptions about evolution (Abraham et al., 2012). They focused on three alternate conceptions identified during interviews with students: that recently developed traits would be more often present in extant species than ancestral traits; that evolution only happens through accumulating enough changes from the ancestral form to become a new species without creating a new branch from the original line; and that as time passed, lineages would become more intricate. Abraham and colleagues added a lab session with exercises about traits that appear in extant and extinct organisms, and measured students’ understanding of the three concepts with a pre- and post-assessment. The results of asking students to confront their alternate conceptions and replace them with
the correct understanding was mixed. Students’ understanding of the frequency of derived traits increased, but the intervention seemed to reinforce the alternate conception about anagenesis and had no influence on the alternate conception regarding the complexity of lineages (Abraham et al., 2012).

However, the research design of this study had some major flaws. First, the researchers interviewed undergraduates at Northeast community colleges and public and private universities to discern which alternate conceptions were common, then used the intervention on students in two other parts of the country. Although the alternate conceptions may have been generalizable to different parts of the country, using one site for initial information gathering and two other sites for intervention research seems problematic. In addition, they created their own concept inventory, which had a lower reliability index than is generally acceptable in educational research (Abraham et al., 2012). This research is one of the few in evolution education that targets community college students in its sample. While Abraham and colleagues did not seem to directly encourage students to confront their alternate conceptions, the intervention attempted to replace students’ alternate conceptions with accurate scientific understanding about the process of evolution. The study by Abraham and colleagues led to use of a validated instrument in my research. In addition, it influenced the creation of the cultural border crossing intervention, which replaced Mr. Gloucester’s previous emphasis on the confront-and-replace pedagogical strategy.

One example of an instructional strategy used by undergraduate biology teachers teaching evolution is the Teaching for Transformative Experiences in Science (TTES) model (Heddy & Sinatra, 2013). In the TTES model, three concepts must be present to lead to a transformative learning experience. First, students must actively use a concept by seeking
related experiences outside of class. Second, students need to experience an expansion of perception, which happens when class content changes the way a student sees the world. Finally, the student needs to value the experience by appreciating the materials that can change his or her worldview (Heddy & Sinatra, 2013). The authors found that teaching evolution through the TTES Model effectively facilitated transformation experience, had a large effect size related to the effectiveness of facilitating conceptual changes, and was significantly associated with enjoyment by undergraduate biology students (Heddy & Sinatra, 2013). The cultural border crossing intervention design in this research was partly based on Heddy and Sinatra’s idea of expanding students’ perceptions by discussing the validity of different sources of knowledge.

Another study measured the effect of a pedagogical strategy that focused on a discussion of religious doctrine in an undergraduate biology class. The study took place at Brigham Young University, a private Church of the Latter-Day Saints (LDS) college that encourages religious discussions in the classroom (Manwaring et al., 2015). As a lack of knowledge about religious doctrines related to evolution can act as a barrier to acceptance of evolution, Manwaring and her colleagues used a quasi-experimental design in which LDS religious doctrine describing their neutral beliefs about the theory of evolution was discussed in one class section and not addressed in the other. The authors hypothesized that LDS students had a general belief that the church held an anti-evolution stance whereas in fact LDS doctrine holds that natural selection and evolution are questions for science and has no official position on evolution. Results showed that students in the section in which religious doctrine about evolution was discussed had statistically significant larger gains in acceptance on the MATE as compared to students in the control section. Students’ MATE scores
increased 1.84 points for each 1 point increase in their understanding of the LDS doctrine on evolution (Manwaring et al., 2015). Interestingly, the gains in acceptance did not correspond to gains in understanding of evolutionary concepts. The students in the control section gained more knowledge on average than the students in the intervention section (Manwaring et al., 2015). While these results were mixed, it is important to note that students accommodated the new information about LDS neutrality on evolution in their worldviews. The study by Manwaring and colleagues led to the creation of the intervention’s lesson about religious doctrine on evolution.

While the study by Manwaring and colleagues offered data about how Mormon students responded to learning about religious doctrine on evolution, it is difficult to know whether these results are generalizable to students holding other religious worldviews. Manwaring et al. point out that “the LDS church is unique in the way its worldwide congregations are united by and adhered to the same doctrine [leading to] a homogenous representative sample of highly religious people” (2015, p. 10). The population in this dissertation research is not comprised of a homogenous group of students; the target students ranged from Atheists to Fundamentalist? Christians to Muslims. In addition, other variables in the Manwaring study such as instructor effect could have led to the larger gain in acceptance of evolution.

A fourth study focusing on student apprehension when learning about evolution involved a collision of worldviews. In this mixed methods study, the researcher wanted to know whether explicit teaching on scientific sources of knowledge through the Nature of Science (NOS) would result in significant change in student apprehension when learning about evolution (Martin-Hansen, 2008). Martin-Hansen gathered data through the Views on
Science-Technology-Society (VOSTS) instrument, students’ assignments, and interviews with students. At the beginning of the class, 37% of the students declared they had previous apprehension or negative feelings about evolution. One clearly described the conflict between religious and scientific sources of knowledge by saying, “Evolution made me question a lot of beliefs that I had, but the main one was that if people were wrong about God creating man, then they could be wrong about the whole heaven concept as well” (Martin-Hansen, 2008, p. 328). Another said, “I was apprehensive because it seemed like if I accepted the theory of evolution then I would be viewed on the same level as an atheist or Satanic person” (Martin-Hansen, 2008, p. 328). These students were obviously unable to construct understandings through collateral learning or cross the cultural border between scientific and religious worldviews before the pedagogical intervention began. However, after completing the course and explicitly learning about the nature of science, students reported less anxiety about evolution learning. One student stated, “I’ve found a view on life that puts my mind at ease and allow(s) me to pursue knowledge without fear” (Martin-Hansen, 2008, p. 329). While more qualitative data is needed to determine which type of collateral learning this specific student is using, this student has undergone a successful border crossing. Martin-Hansen’s evolutionary autobiography assignment was used in this intervention to encourage students to reflect on their beliefs about evolution before the unit began.

Martin-Hansen’s study provides data on how students viewed the Nature of Science within the context of evolution but suffers from several limitations. First, bias was introduced into the study because the researcher was also the class instructor. In addition, the study did not include a control group with which to compare results. Finally, while Martin-
Hansen included a table with pre- and post- VOSTS scores, she did not include any statistical analyses regarding the statistical significance of the gains. Her conclusions did not make it easy to discern in which aspects of NOS the students had made gains in understanding.

**Epistemology and Sources of Knowledge**

People draw from sources other than classroom learning when thinking about science. Therefore, it is important to consider epistemological issues when researching science education. Epistemology is the philosophical study of knowledge and beliefs. The basic components of epistemology include knowledge, belief, truth, and justification. Epistemology asks questions about sources and conditions of knowledge, the limits of knowledge and the justifications of beliefs (Steup, 2017).

**Students’ Sources of Knowledge about Natural Phenomena**

Students construct their worldviews with information from multiple sources of knowledge. First, many students in the United States grow up attending some type of religious services or learning about religion at home from their parents. Therefore, religion is often one early source of knowledge about the physical world for students. For instance, the Bible teaches that living animals are descendants of those on Noah’s ark. A second source of knowledge is science, and students can learn about scientific explanations for natural phenomena at school, at home, or in other informal settings. The law can serve as a third source of knowledge. For instance, many court cases have ruled on biotechnology patents involving the genes of plants, humans, and animals in the past ten years (Chakrabarty, 2017). Finally, students can draw on their own common sense or intuition as a source of knowledge when they ask questions about the world. For example, high school students in one study talked about the “cells” of water and dye. Since students are accustomed to talking about
cells in relation to living things, these students also thought the smallest particles of water and dye must also be cells (Marek, Cowan, & Cavallo, 1994).

**Students’ sources of knowledge about evolution.** Students may use religious, scientific, legal, and common-sense sources of knowledge to think about evolution as well.

**Religious sources of knowledge.** Religion is an integral part of culture and contributes to students’ worldviews. While the majority of religious Americans are Christians, religious pluralism has increased in recent years (Pew Research Center, 2017). Religious sources of knowledge often play a part in students’ understanding of the diversity of life and how heritable traits are passed down to offspring. For instance, Christianity uses the Bible as their primary written source on information. The Bible explains that God created all living things in the Garden of Eden in seven days with Adam and Eve created in God’s image on the sixth day. Later, the Earth was flooded and all living things that were not on Noah’s Ark perished in the flood. Christians often view the stories of the Garden of Eden and Noah’s Ark as the origin of all life on Earth. Other religions have their own stories that explain the creation and existence of living things.

Religious sources of knowledge may play a role in students’ resistance to scientific explanations about the diversity of life on Earth, i.e., the theory of evolution. As far back as 1925, prosecutors at the Scopes Trial argued that evolution should not be taught in public schools because it contradicted scripture (Barbour, 1990). Recent research at three different colleges demonstrated that college students sometimes believe evolution cannot be correct because it contradicts the Biblical story of creation and found that almost all students came to class identifying as either a creationist or an evolutionist (Kelly et al., 2016). While many research studies like these collected and analyzed quantitative data on evolution
understanding and acceptance, few have explored the intrinsic and extrinsic factors that lead to understanding and acceptance of evolution (Glaze & Goldston, 2015).

**Scientific sources of knowledge.** Students also use scientific knowledge when learning about the diversity of life and how heritable traits are passed down to offspring. They learn about evolution as an explanation for this process in formal and informal science experiences. At times, however, their scientific knowledge may be inaccurate and lead to incorrect assumptions about how evolutionary processes work. For example, American middle school students often learn that cells are composed of organelles that have functions within the cell. They may then infer that all of an organism’s traits must have functions as well. Sometimes students believe that that “a trait’s current ability to perform a beneficial function is the only factor needed to explain why that trait came into being” (Kelemen, 2012).

Not every concept learned in one science class can be applied to processes learned about in other science classes. Another example involves the use of the word “pressure”. Evolution learners often think of evolutionary pressure as a force, such as the forces that lead to motion, which they have learned about in a physical science class. In the case of evolution, pressure is not a causal agent that pushes evolution toward a goal, but instead an environmental factor that leads to differential survival within a population, which leads to evolutionary change (Rector, Nehm, & Pearl, 2013). While instruction in scientific sources of knowledge can often be beneficial when learning about how the process of passing down changes in heritable traits leads to the diversity of life, they do not guarantee understanding of the theory of evolution.
Legal sources of knowledge. As previously mentioned, the Scopes Trial of 1925, when a substitute teacher was found guilty of teaching evolution in a K-12 classroom in Tennessee (Hermann, 2013) often comes to mind when anyone considers evolution and the law. However, other more recent court cases exist which offer legal sources of knowledge about teaching and learning evolution. In 1981, the Arkansas legislature passed a law that creationism must be given equal time and treatment alongside evolution in high school biology curriculum. However, this law was overturned by the U.S. District Court in 1982 because it favored a particular religious viewpoint, thereby violating the separation of church and state (Barbour, 1990). In 1987 the U.S. Supreme Court ruled in Edwards v. Aguillard that Intelligent Design could not be taught in K-12 science classrooms because it advanced religion (Pobiner, 2016). Subsequently, Intelligent Design advocates removed references to God and instead concentrated on empirical evidence against evolution. Proponents for Intelligent Design offered the theory that life is too complex to have arisen without an unnamed creator as an alternative to creationism (Pobiner, 2016).

Although the Intelligent Design movement changed tactics and moved away from the religious aspect of Intelligent Design, in 2005, federal courts ruled in Kitzmiller v. Dover Area School District that Intelligent Design was a form of creationism and therefore not allowed to be taught as public-school science (Pobiner, 2016). In Peloza v. Capistrano Unified School District the court ruled that teachers are not “ordinary citizens” and therefore cannot use the right to free speech to discuss their own personal beliefs in the classroom (Hermann, 2013). Despite these and other legal precedents (see Pobiner, 2016 for a thorough list of cases involving evolution), it is important to remember that the law does allow creationism to be taught in science classrooms if it is discussed neutrally, various cultures’
creation stories are shared, and the focus is on separating science and religion (Hermann, 2013).

**Common sense sources of knowledge, including intuition.** Several studies have identified alternative conceptions college students hold about evolution and natural selection that are based on common sense sources of knowledge. Cunningham and Wescott used a self-designed instrument given to 547 students in an Introduction to Biological Anthropology class to measure teleological, essentialist, and anthropocentric alternative conceptions (2009). Many alternative conceptions were identified, including those based on teleological cognitive construals (evolution is driven by “need”) and vernacular alternative conceptions surrounding the misuse of “theory”. Interestingly, the researchers found that students most often agreed with positively worded statements, whether those statements were accurate or based on alternative conceptions (Cunningham & Wescott, 2009).

**Effects of sources of knowledge on evolution thinking.** Much research has been done identifying alternative conceptions or examining how various sources of knowledge affect students’ learning of evolution (e.g. Borgerding et al., 2017; Cavallo & McCall, 2008; Demastes, Good, & Peebles, 1995; Doudna, 2016; Ha, Haury, & Nehm, 2012; Kelly et al., 2016; Rector et al., 2013). A collision of various sources of knowledge often affects students’ thinking about evolution. In fact, “evolution is one of the few areas of science in which there is both wide-scale rejection and acceptance based on nonscientific concerns” (Abraham et al., 2012, p. 153). Most epistemological research assumes that students’ epistemologies brought to the classroom are inferior to the ones the educators are using to teach (Bang & Medlin, 2010).
One research study has shown that being aware of students’ epistemological resources is a valuable tool in teaching science. When learning about abiotic factors, Native American middle school students in the Chicago area experienced tension because their elders would say rocks and water are alive, but science teachers would say they are not (Bang & Medlin, 2010). After observing this type of thinking, a team of researchers and teachers revamped a forest biology class to consider Native views on the importance and usefulness of plants and emphasize the idea that all living things are related. Students were also taught about the history of the area and how their ancestors’ association with it changed over the years. Interviews indicated that students shifted from thinking they learned about science only in school to expanding the sources of knowledges and contexts in which they learned about science to those related to their community (Bang & Medlin, 2010). These students were able to expand their thinking about science and sources of knowledge about natural phenomena explained by science (as well as by their cultural beliefs), but this is not always the result of tension between two sources of knowledge while learning. The pioneering research of Bang and Medlin is promising and aligns with the cultural border crossing framework used in this research.

*When conflict occurs.* Students often experience conflict when studying evolution and many research studies have focused on this conflict. Most of the studies focus on how students’ religious beliefs and culture are linked to a lack of acceptance of evolution (Barnes & Brownell, 2017; Heddy & Nadelson, 2013; Moore, 2008; Nadelson & Hardy, 2015; Rissler et al., 2014; Tollini & White, 2010). One study showed that 57% of students in an introductory biology course for non-majors, similar to the one focused on in this research, believed that creationism should be taught as part of the public-school curriculum (Moore,
Another study found that 34% of undergraduate students believed that Intelligent Design was a plausible alternative theory to that of evolution, and another 22% of students thought Intelligent Design was a better theory (Tollini & White, 2010). Many other studies explore various options that might result from conflict during the study of evolution.

Conflict when studying evolution can also arise from a difference between students’ emphasis on religious sources of knowledge and professors’ emphasis on scientific sources of knowledge to explain what led to the diversity of life on Earth. In an interview study with college biology instructors (n=32), the majority of instructors did not try to ameliorate conflict between religious and scientific thinking while teaching about evolution (Barnes & Brownell, 2016). Some reasons for the lack of attention to the conflict between religious and scientific ways of thinking were that instructors thought that relatively few students felt anxious when studying evolution due to religious beliefs, that the instructors did not have the training to implement related pedagogical strategies, the instructors’ own negative beliefs about religion, and their beliefs about the mutual exclusiveness of religion and science (Barnes & Brownell, 2016).

Rejection of new source. As Aikenhead and Jegede explained, some students are unable to cross borders that exist between two sources of knowledge for the same phenomenon (1999). For example, in their research, Hanley and colleagues found that a significant portion of British high school students resisted learning about evolution in science class (Hanley et al., 2014). These students valued beliefs over facts and believed that science and religion cannot and should not be reconciled. These beliefs often led to defensiveness when students were asked to examine both science and religion as valid sources of knowledge that account for the diversity of life on Earth. The authors believe that students
who rejected the new scientific source of knowledge about evolution might find school alienating in general because of their inability and disinterest in reconciling different lines of knowledge (Hanley et al., 2014). The cultural border crossing and collateral learning frameworks in my research account for reconciling different lines of knowledge, building on this promising insight by Hanley and colleagues.

In a study of American undergraduate students, Romine and his colleagues found that a small portion of students (6%) rejected both the validity and the facts associated with evolution, thereby rejecting the new source (Romine, Walter, Bosse, & Todd, 2017). These students rejected the new source of information (science) because their beliefs in religious sources of knowledge about how diversity of life on Earth arose were stronger. This study only collected quantitative data which precluded offering more information about how students handled the process of rejecting science.

Beliefs in specific aspects of religion can also lead to rejection of a new, scientific source of knowledge when learning about evolution. For instance, the belief in a literal interpretation of the Bible, especially the book of Genesis, is a more difficult obstacle to overcome for acceptance of the scientific theory of evolution in comparison to a more general belief that God exists as a higher power (Barnes & Brownell, 2018). The strength of the religious belief itself can also contribute to the rejection of scientific sources of knowledge about evolution, as some students might be more committed to their belief in the literal interpretation of Genesis than others (Barnes & Brownell, 2018). Students’ personal characteristics can also influence their choice of religious beliefs over scientific beliefs. For example, Billingsley (2004) found that Australian undergraduate students chose religious or scientific beliefs based on personal characteristics. One explained, “I am looking for an
answer that catches my interest. I’m an imaginative kind of person; I’m not someone who cares if it’s wrong or right,” while another said, “I am seeking a view that makes me happy” (Billingsley, 2004, p. 251).

Replacement of original source. Sometimes students might replace the original belief with another, based on a different source of knowledge. Several papers have explored conditions in which there was a strong increase in students’ acceptance of evolution. In one study, gifted high school students participated in seminars about issues about such as the false dichotomy between science and religion and the perceived relationship between evolution and racism. Differences in students’ scores on the Measure of Acceptance of the Theory of Evolution (MATE) administered before and after the evolution unit showed a substantial increase in evolution acceptance by the students. In fact, the greatest increases in students’ acceptance of evolution happened in students who initially rejected evolution (Wiles & Alters, 2011). Another study explored the change in student acceptance of evolution in a course on behavior and evolution. Shtulman and Calabi (2013) found that students with lower pre-test scores showed greater increases than students with higher pre-test scores, especially related to evolution as a plausible and fruitful theory. Results from both studies demonstrated that students sometimes replace an original schema regarding evolution with a new, science-based evolution schema. When replacement happens in conceptual change, it is usually predicated by four conditions: dissatisfaction with current beliefs, understanding of the new belief, fruitfulness of the new belief, and plausibility of the new belief (Posner, Strike, Hewson, & Gertzog, 1982).

Co-existence of two sources. Many times, students can find some sort of reconciliation between two sources of knowledge regarding evolution. For example, in the
study by Hanley and colleagues referenced earlier, students in the “Explorer” group actually enjoyed reconciling information gleaned from scientific and religious sources. Students in this group usually had strong critical thinking skills and were satisfied despite a lack of resolution during conflict (Hanley et al., 2014).

However, co-existence of two sources does not always lead to some type of reconciliation. Cobern believed that some students undergo cognitive apartheid, a process in which they partition off what they believe from what they do not (1996). Recent research yielded a grounded theory for cognitive apartheid of evolution concepts. Part of this theory explains that students undergoing cognitive apartheid seem to be searching for an integrated worldview. For example, one student said, “God created the earth in seven days, but the Bible…doesn’t specify how long a day is…and that kind of came together with what one of my teachers said how…God could have created animals through evolution, and so I kind of piece those together as a possibility” (Hermann, 2012, p. 623). Although this student has not completely assimilated the information, he is attempting to find an integrated view on evolution using religious and scientific sources of knowledge. He has also been able to successfully cross the border, albeit with some difficulty, between scientific and religious knowledge and his thought process indicates secured collateral learning. This type of border crossing most likely accounts for the 38% of people who believe in theistic evolution according to the most recent Gallup poll (Swift, 2017).

After examining the literature on how sources of knowledge affect students’ acceptance of evolution, it is apparent that there is a continuum of reactions that occurs when information from different knowledge sources collide ranging from complete rejection to complete replacement with many integrative stops along the way. This is probably due in
part to the fact that there is no universally accepted explanation for the natures of science and religion and the relationship between them (Billingsley, 2013). In order to find out what factors influence students’ reactions, evidence about their worldviews and how they affect students’ learning must be collected.

Assessing Understanding and Acceptance regarding Evolution

Understanding and accepting a concept often involve two very different ways of thinking. It is not surprising, therefore, that much research has been undertaken regarding student acceptance and understanding of evolution. Over 200 studies on student acceptance of evolution have been published since the early 1980s (Barnes & Brownell, 2018).

Educational researchers offer different definitions of accepting and understanding evolution. For instance, Barnes and Brownell (2018) define student acceptance of evolution as “the extent to which a student finds evolution to be an accurate scientific explanation for the diversity of life on earth” (p. 37), while Smith (2010) defines acceptance as when a student thinks that evolution is the best explanation for changes in species. Smith’s definition is more specific than Barnes and Brownell’s, indicating that species change, at least in part, leads to the diversity of life on Earth. For this research, the following definition of acceptance will be used: the student’s reliance on evolution as the best explanation for how presently existing species arise and change through natural processes.

Many educational researchers have examined the relationship between acceptance and understanding of evolution. Research shows that students who understand how evolution works but do not accept it as a valid explanation for the diversity of life are not likely to use evolution-based thought processes when making decisions related to biology, such as management of wildlife in their local area (Sinatra, Southerland, McConaughy, &
Demastes, 2003; Southerland & Nadelson, 2012). Prior to delving into students’ worldviews about evolution and how the diversity of life on Earth came to be, one must first accurately measure understanding and acceptance of evolution. This section of the literature review details the instruments used to measure knowledge and beliefs about evolution in my dissertation research.

Assessing Understanding of Natural Selection as a Process which Drives Evolution

Concept inventories are often used to measure students’ knowledge. One instrument used frequently in evolution education research is the Conceptual Inventory of Natural Selection (CINS), developed by Anderson, Fisher, and Norman (2002). See Appendix A for sample questions. The CINS measures understanding of natural selection concepts. It includes twenty multiple choice questions that contain distractors with common alternative conceptions about phenomena explained scientifically through natural selection and evolution. The authors have found that the CINS is appropriate for assessing the knowledge of high school students, biology majors and non-biology majors at ethnically diverse institutions (Anderson et al., 2002). Although the CINS is, like most instruments, imperfect, it has been widely used in evolution education research (Nehm & Schonfeld, 2008). The CINS is discussed further in the methods section.

Assessing Acceptance of Evolution

A second instrument discussed in the literature is the Measure of the Acceptance of the Theory of Evolution (MATE), which was designed by Rutledge and Warden (1999). See Appendix B for MATE questions. This instrument contains twenty Likert-scale items that can shed light on students’ agreement or disagreement with various parts of evolution. Although the instrument was originally designed to assess teachers’ acceptance of evolution
(Rutledge & Warden, 1999), it has also been successfully used to measure undergraduate students’ acceptance of evolution (Borgerding et al., 2017). More details about the MATE including reliability and validity will be discussed in the methods section.

The MATE is the most widely used evolution acceptance instrument and has been used in over 24 studies since its publication in 1999 (Romine et al., 2017). However, other instruments exist that have been used to measure evolution acceptance by researchers. The Inventory of Students’ Acceptance of Evolution (I-SEA), a 24-item Likert scale instrument, was developed by Nadelson and Southerland (2012) and focused on distinguishing between understanding of evolution and acceptance of evolution. The Generalized Acceptance of Evolution Evaluation (GAENE) is a 16-item Likert scale instrument that has also been used by educational researchers (Smith, Snyder, & Devereaux, 2016). The MATE was chosen because it is well-validated and accepted (Romine et al., 2017). This will allow me to compare results of this research with other studies.

Cultural Border Crossing and Collateral Learning: Support for Evolution Learners?

Some students’ perspectives are that their evolution instructors do not always acknowledge students’ worldviews when learning about the process that led to the diversity of life on Earth. Religious students (n=28) at an R1 university in the Southwestern US explained that instructors had joked about the religious students, showed anger toward religious students, dismissed religious ideas as irrelevant or ridiculous, and created a classroom environment in which students felt unwelcome or unable to discuss their worldviews on evolution (Barnes, Truong, & Brownell, 2017). Whether instructors agree with their religious beliefs, students’ views on evolution are heavily affected by their
worldviews. Results from this study led to the interview question about how students felt in class during the evolution unit.

Worldviews have a large impact on students’ education. For instance, researchers who examined the worldviews of Native American Kickapoo students at home and in the science classroom found that significant differences in these two worldviews would prevent the Kickapoo students from being completely successful in the science classroom (Allen & Crawley, 1998). Waldrip and Taylor (1999) investigated how the Western worldview held by a high school on a South Pacific island permeated the non-Western worldviews held by high school students there. They found that the two worldviews were in opposition with each other and that a Western worldview was not likely to be easily accepted by the students living in a traditional society. Students in the previously-mentioned study of college biology students in the Southwestern US felt that they would be unable to pursue a career in biology because other biologists would perceive them negatively due to their religious worldviews (Barnes et al., 2017). These two studies influenced the cultural border crossing intervention by indicating the validity of multiple sources of knowledge and worldviews.

Recent research attempts to identify pedagogical practices that can address religious and cultural differences between instructors and students in evolution. Barnes and Brownell (2018) interviewed 32 Christian university instructors about their practices and experiences teaching evolution. Instructors reported that instructional practices they viewed reduced perceived conflict between science and religion included presenting students with religious scientist role models, teaching the bounded nature of science, presenting a spectrum of views on the relationship between evolution and religion, and using an inclusive teaching philosophy for students with varying worldviews. Christian university instructors reported
that students challenged them frequently about evolution, but that the students seemed comfortable discussing these issues with their instructors. Instructors felt that such discussions were opportunities for growth and reflection. One instructor explained, “If a student only receives instruction on the ‘cold concepts of evolution’ (e.g., the processes of natural selection…), but does not attend to the ‘hot’ motivational factors of learning evolution (e.g., students’ perception that they must reject God to accept evolution), then we may lose the opportunity to increase student engagement with evolution” (Barnes & Brownell, 2018, p. 54). This work by Barnes and Brownell led to using an inclusive, discussion-based lesson format in the intervention.

When opposing worldviews are present, it is naïve to assume that students will confront their alternative conceptions, wholeheartedly accept new knowledge after reflection and critical thinking, and then replace incorrect knowledge with correct knowledge. One must consider the possibility that sometimes one worldview is not simply replaced by another.

Cultural Border Crossing

Instead of simply replacing one worldview (with its preferred source of knowledge) with another, students may need to navigate between the two worldviews, through a process called cultural border crossing. In the seminal paper on cultural border crossing, Aikenhead discussed how students move from their out-of-school cultures surrounded by family and friends, into the culture contained within the walls of the science classroom. In one example provided by Aikenhead, a Canadian First Nations student spoke so quietly, a norm of his culture, that his science teacher could not hear him and was subsequently scolded for not speaking up. Although this student had crossed through the doorway into the science
classroom, he had not successfully crossed the cultural border between his home and the science classroom. Another student avoided geology classes throughout his entire undergraduate career because he did not want to spoil his aesthetic ideas about nature’s beauty (Aikenhead, 1996).

The first type of border crossing described by Aikenhead and Jegede, successful border crossing, occurs when a student moves flexibly between the concepts held as correct by both cultures while not disregarding the “truth” found on either side of the border (Aikenhead & Jegede, 1999). According to Aikenhead and Jegede (1999), sometimes students are not able to successfully navigate the border between cultures. If a student is unable to fully cross the border, one of three things can happen instead. First, managed border crossing occurs when a student learns the conflicting material (that rain is caused by an excess of moisture in clouds rather than God crying) for the sake of the test and maybe even attempts to assimilate it into what he already knew through his out-of-school culture. As one might expect, managed border crossing does not lead to optimal learning in the classroom. Second, hazardous border crossing occurs when a student resists assimilation, but memorizes what is needed to be successful in the class. Third, impossible border crossing occurs when a student would rather drop out than attempt to resolve the cognitive conflict that occurred when the at-school culture challenged out-of-school culture.

Collateral Learning

Collateral learning is a cognitive mechanism that occurs when learners construct two sets of concepts, such as one religious concept and one scientific concept, alongside each other with minimal conflict (Aikenhead & Jegede, 1999). The example of collateral learning can be seen when considering a rainbow. Aikenhead and Jegede explain:
in the culture of Western science, students learn that the refraction of light rays by
droplets of water causes rainbows; in some African cultures, a rainbow signifies a
python crossing a river or the death of an important chief. Thus, for African students,
learning about rainbows in science means constructing a potentially conflicting
schema in their long-term memory. Not only are the concepts different (refraction of
light versus pythons crossing rivers), but the epistemology also differs” (1999, p.
276).
The collateral learning mechanism is very different from previous theories, such as Piaget’s,
because it allows for students to hold two concepts about the same phenomenon.

Aikenhead and Jegede postulated four types of collateral learning which occur along
a continuum. First, *parallel collateral learning* occurs when schemata are
compartmentalized and students only access one schema at a time (Aikenhead & Jegede,
1999). For instance, if a student discusses how God literally made Eve from Adam’s rib at
church while recognizing that men and women have the same number of ribs in anatomy
class but does not ponder why men do not have one less rib (if all men are descended from
Adam), parallel collateral learning is taking place. In parallel collateral learning, the two
schemata do not interact, but instead the student chooses which schema to access based on
context (Aikenhead & Jegede, 1999).

A second type of collateral learning is *dependent collateral learning*. In dependent
collateral learning, a student can retain and modify their existing schema when confronted
with new information. In this case, the student is usually unaware that the two schemata
conflict and that the process of amalgamation is occurring (Aikenhead & Jegede, 1999). An
example would be a mother who gives both Western medicine and folk-based remedies to
her sick child and does not consider that these solutions come from two different sources of medical knowledge.

At the other end of the continuum lies secured collateral learning, the third type. Secured collateral learning occurs when there is interplay between the competing schemata and the conflict is somehow consciously resolved (Aikenhead & Jegede, 1999). The learner could keep both schemata, or they may create a new schema that combines both schemata. In this example, the mother would research the efficacy of both the Western medicine-based and folk-based remedies she administers to her sick child, and create a plan using the best of both sources of medical knowledge.

The fourth type of collateral learning, simultaneous collateral learning, is difficult to facilitate in the classroom because it usually happens through coincidence. In simultaneous collateral learning, which is found between parallel and dependent collateral learning on the continuum (see Figure 2), a schema from one culture can facilitate the understanding of a similar schema in the other culture (Aikenhead & Jegede, 1999). For example, a Paiute student might understand more about avian mating behavior in a zoology class because he was taught at home to be like an eagle, because it mates for life.

Figure 2. Collateral learning continuum. Parallel collateral learning holds two separate lines of knowledge that do not interact. Simultaneous collateral learning occurs when one source of knowledge facilitates the understanding and acceptance of another source of knowledge. Dependent collateral learning occurs when a learner assimilates new information and modifies, but does not discard, the original type of knowledge. Secured collateral learning happens when the two types of knowledge are intertwined and used and any conflict between the two is resolved. Continuum created based on descriptions from Aikenhead & Jegede, 1999.
Of the three possible outcomes of a collision between sources of knowledge (rejection, replacement, and coexistence), collateral learning – involving coexistence of beliefs - has been studied least in regard to evolution. The next section of this literature review will revisit the topics discussed in this section, with a focus on evolution teaching and learning.

**Collateral learning and evolution learning.** Three of the four types of collateral learning are found in research on how students acknowledge multiple sources of knowledge when learning about evolution. First, parallel collateral learning is like Cobern’s (1994) cognitive apartheid concept, where students maintain two parallel, but separate, sets of knowledge. The guidelines for how those two sets of knowledge are compartmentalized seem to depend on the student. For instance, a student exhibiting parallel collateral learning might access his knowledge of the Koran while talking about the creation of humans with Muslim friends and family while considering natural selection while studying how mosquitofish evolve in his labwork.

Dependent collateral learning occurs when students attempt to modify their original schemata when confronted with new information. Anita, a British middle school student, explained how she assimilated her original religious schema with what she learned in science class, “…all the different theories, they clash, but like when you think about it deeper like with the big bang, we don’t know why it happened, it could’ve been God creating the universe with the big bang…we can’t deny that the big bang probably did happen, but we still don’t know what like made it happen” (Taber, Billingsley, Riga, & Newdick, 2011, p. 1010). In Anita’s point of view, religious and scientific knowledge could both answer questions about the Big Bang.
Secured collateral learning is present when “the reinforcing of schema learned in one world view by a similar one from another begins to occur” (Jegede, 1995, p. 120). For example, one American undergraduate student explained that he “became more spiritual when considering that science does not rule out the presence of a God” (Martin-Hansen, 2008, p. 333). For this student, two worldviews that were formerly oppositional began to support each other during his study of evolution and the nature of science. The idea that science was not intent on disproving religion as an important source of knowledge allowed for secured collateral learning in this student. Again, this secured collateral learning could be responsible for the fact that 38% of Americans accept theistic evolution (Swift, 2017). While theistic evolution is not the optimal scientific belief, this type of secured collateral learning might be the first step toward a robust scientific understanding of evolution as the process that leads to the diversity of life on Earth. Parallel and/or dependent collateral learning could be first steps toward secured collateral learning.

This research will examine what type(s) of collateral learning might be present after students with religious worldviews participate in the cultural border crossing/collateral learning intervention. See Figure 3 for possibilities.
Students who have only religious worldviews prior to the intervention may afterward demonstrate parallel collateral learning, in which their religious and scientific worldviews are still compartmentalized. The second possibility is that students show dependent collateral learning, in which their religious worldview influences their scientific worldview or vice versa. The last two possibilities are versions of secured collateral learning. Students will retain both worldviews through

Figure 3. Possible collateral learning outcomes.
allowing them to reinforce each other or creating a new, merged worldview. Based on descriptions from Aikenhead & Jegede, 1999.

**Summary**

This literature review demonstrates that evolution is a well-accepted scientific theory to explain the process which led to the diversity of life on Earth and is an underlying theme in biology. However, there are many obstacles that make learning about evolution difficult for students. Confusion or misunderstandings about the mechanisms driving evolution can lead to conclusions about the usefulness or validity of evolution as a natural process. The process of conceptual change has long been considered necessary for students to accommodate or assimilate new information with which they are confronted. However, current research shows that students can also reconcile their religious beliefs and scientific beliefs so as not to undergo the anxiety that might come along with replacing their original beliefs.

While several studies exist that examine how sources of knowledge affect students’ knowledge and beliefs about evolution, most focus on conceptual change and replacing alternative conceptions rather than cultural border crossings, and none use an intervention that focuses on the differences between religious and scientific sources of knowledge when working with community college biology students. Chapter 3 explains how the dissertation research used an intervention about the validity of different sources of knowledge to answer different questions about life rather than pushing for conceptual change in students learning about evolution, to allow for cultural border crossing and its cognitive mechanism, collateral learning. In addition, how data collection procedures helped examine community college students’ cultural border crossings and collateral learning experiences when learning about evolution is illustrated.
CHAPTER 3

Methodology and Research Design

This chapter presents the methods to collect and analyze data to examine the two research questions: RQ1) How do community college biology students’ understandings and acceptance of evolution change after a pedagogical intervention focused on the cultural border crossing model? and RQ2) How do community college biology students navigate border crossings that might be necessary due to conflicting religious and scientific beliefs using some form of collateral learning? Chapter Three first discusses the rationale for using mixed methods as a research approach, then present information on the research setting, sample and data sources, and data collection and analysis methods. Finally, potential weaknesses in this research are identified and validity, reliability, and limitations are discussed in greater detail.

Mixed Methods Rationale

This study uses a sequential explanatory mixed methods design, which collects and analyzes quantitative data prior to the collection and analysis of qualitative data (Creswell & Plano Clark, 2011). The key components of mixed methods design in general include rigorous collection and analysis of both qualitative and quantitative data, the mixture of these two data forms with priority given to either qualitative or quantitative, and the grounding of mixed methods procedures within theoretical and philosophical frameworks (Creswell & Plano Clark, 2011). This study prioritizes quantitative data, which was collected and analyzed in order to choose a group of students who span the continuum of evolution acceptance; see Figure 4.
This research responds to several needs mentioned by Creswell and Plano Clark (2011), including the need to enhance a study with a second method. The mixed methods research design helps illuminate the process of cultural border crossing in undergraduate community college Biology students. Collecting quantitative and qualitative data enables the researchers to ask questions about the effectiveness of the intervention in addition to the lived experience of students during the intervention.

**Research Setting**

Research was done at a community college in the Southeastern United States. This community college was selected as the research setting to focus on a population who had rarely been previously researched in regard to evolution teaching and learning. The community college also offered a demographic of students more like the general public than a university might. In addition, the researcher had a contact there that might help successfully recruit a professor willing to enter a research partnership.

This community college has multiple campuses located in different parts of a large county that contains rural, suburban, and urban areas. This research was located at the
original branch of the community college, located on the edge of a large city. The introductory biology class in which the research was conducted is discussed in the next section.

Sample Size and Characteristics

The sample includes two sections of BIO 110 (Principles of Biology), a class that is designed for students who will not be majoring in a science. One section participated in BIO 110 in the fall of 2017, and the other section took BIO 110 in the spring of 2018. Each section had between 25-35 students at the beginning of the semester. About \( \frac{1}{4} \) of the students dropped the class before the end of the semester due to a failing average. Many of the students in the class plan to transfer to a larger four-year college or university in the state.

Professor Gloucester (a pseudonym) was the professor of both BIO 110 sections. He has Bachelor’s and Master’s degrees in Biology, has taught at the community college level for nine years, and teaches two sections of BIO 110. He was eager to assist with this research from the start as he found evolution to be the topic students were least successful with despite many different interventions. Students attended their classes for two lecture periods and one lab period each week and topics covered included biology, genetics, evolution, and ecology. Professor Gloucester devoted approximately ten to twelve hours of lab and lecture time to the evolution unit. The instructional approach consisted of lectures, classroom discussions, and hands-on, group lab activities.

**Control group.** The Fall 2017 section of BIO 110 served as the control group. The researcher attended all lecture classes related to evolution and wrote field notes on the pedagogical strategies used, student participation, and the types of questions asked by students. All students (N=48) took the CINS and MATE before the evolution unit started
and retook them after the last lab related to evolution at the beginning of December. A heterogenous group of students (n=5) was chosen to interview based on their MATE scores. The lowest MATE score in the group is 35 (very low acceptance of evolution) and the highest MATE score in the group is 99 (very high acceptance). Interviews took place in early December at the end of the semester. See Appendix C for interview protocols, which were created based on the cultural border crossing and collateral learning frameworks. Control group data is discussed more thoroughly in Chapter Four, with a focus on comparing the quantitative data between control and intervention groups.

**Intervention group.** This study also includes an intervention section taught with a pedagogical focus on cultural border crossings. Professor Gloucester’s intervention was created with guidance from the principles of cultural border crossing and collateral learning (Aikenhead, 1996; Aikenhead & Jegede, 1999). The intervention was scripted and observations and field notes from the researcher assessed fidelity. Using the script, Professor Gloucester led discussions on epistemological sources of knowledge, creation stories of various cultures, religious doctrine related to evolution, and policy decisions related to evolution and religious beliefs. The intervention lasted for approximately 20 minutes of every 50 minute class period during the evolution unit. Since the intervention comprised 40% of the class time, it allowed Mr. Gloucester to meet his evolution curriculum goals by adding one day to the unit as compared to how he taught it in the control section while still adding an effective dosage of the intervention. See Appendix D for the full lesson plans. See Table 1 for a summary of these daily discussions.
### Table 1
**Intervention Lesson Descriptions and Related Concepts**

<table>
<thead>
<tr>
<th>Day</th>
<th>Key intervention activities</th>
<th>Goal of Activity</th>
<th>Theoretical/Empirical support for activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Student pairs completed a card sort where they classified questions in accordance to what knowledge source they would look to for answers.</td>
<td>Collateral learning: students understand that more than one source of learning can be valid as part of their worldview and allows for easier border crossing</td>
<td>Barnes &amp; Brownell (2018): students’ beliefs that only one source of knowledge was valid was an obstacle to evolution acceptance</td>
</tr>
<tr>
<td>Two</td>
<td>Students learned about the Haida creation myth, researched a creation myth of another culture, and shared with the class.</td>
<td>Collateral learning and CBC: students understand that there are many beliefs that serve as part of cultural worldviews</td>
<td>Barnes &amp; Brownell (2018): students’ beliefs that only one source of knowledge was valid was as an obstacle to evolution acceptance</td>
</tr>
<tr>
<td>Three</td>
<td>Student pairs examined the religious doctrine related to evolution for one religion and collaborated on a chart of religious doctrine on evolution.</td>
<td>Collateral learning and CBC: students learn about various religious doctrines that have a neutral religious stance toward evolution therefore adding a scientific worldview component which does not contradict most religious doctrines</td>
<td>Rissler et al. (2014): students’ religious beliefs affect their acceptance of evolution; Manwaring et al. (2015): students’ knowledge of LDS doctrine on evolution (neutral stance) increased evolution acceptance.</td>
</tr>
<tr>
<td>Four/Five</td>
<td>Students discussed school board scenario asking whether creationism or ID fit into science ed.</td>
<td>Collateral learning-students define science and how it relates to their choices regarding evolution</td>
<td>Martin-Hansen (2008): one obstacle to evolution understanding/acceptance is that students confuse the science behind evolution with belief/faith systems</td>
</tr>
</tbody>
</table>

Professor Gloucester began each lecture period with mini-lessons listed in the table above related to the intervention. Prior to the first lecture class, students wrote “Evolution Autobiographies” for a homework assignment, as used by Martin-Hansen (2008). (See
Appendix E for assignment.) These assignments serve as pre-assessments to determine students’ beliefs about and acceptance of evolution prior to instruction. Evolution Autobiographies were graded by Professor Gloucester for completion, but not for accuracy. During the first lecture class, the mini-lesson began with a discussion about epistemologies and sources of knowledge (such as science, religion, the law, philosophy, common sense) in class. Students were asked to participate in a card sort with a partner of their choice. Student pairs received index cards with questions on them such as “How did human life on Earth begin?”, “What happens after we die?”, etc. and sorted the questions into epistemological source categories of their own creation. See Appendix F for questions. Professor Gloucester circulated around the room, checking on the student pairs’ groupings. The researcher took pictures of the students’ card sorting systems for later use in qualitative data analysis during this time. Afterwards, student groups shared out their sorting systems, but the discussion was rather minimal, as this was the first lesson of this nature. After the mini-lesson, Professor Gloucester lectured on the biological species concept and speciation. He asked questions during the lecture to check for understanding.

During the second class lecture, students learned about different creation stories. Professor Gloucester presented several creation myths, including the Biblical story of Adam and Eve and the Haida story of Raven and the first man (McWilliams, 1997). Students discussed what types of questions these sources of knowledge can answer. Then students formed self-selected groups and researched a creation story of any culture. Groups then shared the examples they found with the class. Notes were taken on the discussion that ensued. After the mini-lesson, Professor Gloucester finished the lecture on the biological
species concept and then discussed the four mechanisms of evolution: natural selection, gene
flow, genetic drift, and mutation.

In the third class lecture, students discussed how religion and science are related. Previous research demonstrates that college students do not accept evolution when they feel it contradicts their religious beliefs (Rissler et al., 2014). This part of the intervention was designed to increase students’ knowledge of various religious doctrines related to evolution as Manwaring et al. (2015) found that increased knowledge about religious doctrine led to increased acceptance of evolution. Students were grouped in pairs and given a religion to research. Students were not asked to research their own religions (if applicable) in order to avoid any additional tension that might be caused by discussing personal religious worldviews in a biology class. Students were assigned religions whose doctrines regarding evolution could be found through the Pew Research Center website (http://www.pewresearch.org/topics/evolution/). The list of religions included: Catholicism, Islam, Mormonism, Southern Baptist, Methodist, Pentecostal Holiness, Buddhism, Hinduism, Presbyterian, Judaism, Episcopalian. Each pair used the internet to search for the doctrine about evolution affiliated with their assigned religion. When completed, the students filled in a chart on the whiteboard about the different religions’ doctrine concerning evolution. The only religion with an anti-evolution doctrine was that of the Southern Baptist religion (Robinson, 2005). Professor Gloucester then led a short class discussion about the relationship between evolution and various religions’ beliefs about the process that led to the diversity of life on Earth. When the mini-lesson ended, Mr. Gloucester continued his lecture on genetic drift and gene flow.
In the fourth class lecture, students had a brief discussion about alternative conceptions related to evolution, and Professor Gloucester showed a power point with various typical evolution alternative conceptions explained. This was the only part of the mini-lessons that Professor Gloucester had previously used in teaching BIO 110. Professor Gloucester usually assigns this power point as homework but wanted to discuss it during class as part of the intervention. At the end of the class, he distributed the School Board Scenario assignment, which he explained was homework. Afterwards, he returned to lecturing about selection and the factors that affect it. Mr. Gloucester finished the class meeting by discussing important vocabulary words such as adaptation and fitness.

Finally, in the last class lecture related to evolution, students brought in the School Board Scenario assignment. This assignment was designed to examine how students relate policy decisions to their definition of science (M. Bloom, personal communication, 2018). Professor Gloucester tallied up the percentage of students who believed that Creationism and Intelligent Design should be taught in the science classroom and wrote the percentages on the board. Willing students discussed their thoughts on this topic and then all students handed in the assignment. Some students discussed religious views on evolution from the perspectives of their own religions, such as a Muslim student who shared the views of different sects on evolution. Mr. Gloucester referenced the often-seen drawing of an ape evolving into a modern human during the class. This led into a lecture on criticisms of evolution and Mr. Gloucester finished the class meeting by discussing disruptive and directional selection.

These four mini-lessons built on the cultural border crossing and collateral learning frameworks by allowing the students to explore sources of knowledge, worldviews, and the relationship between religion and science. The mini-lessons were scaffolded in a manner that
began with a broad view of knowledge and ended with a specific application, discussing how one might employ religious and scientific views on the diversity of life on Earth when making a civic decision about education. Results from the intervention activities are discussed further in the results section.

Data Collection Methods

This section contains information on the quantitative and qualitative methods used in data collection as well as the specific data sources. Appendices A-I are found at the end of this paper and contain details about data collection methodology.

Quantitative Data Collection

Two instruments were used to collect quantitative data in this study. The Concept Inventory of Natural Selection (CINS) and the Measurement of the Acceptance of the Theory of Evolution (MATE) were used to collect quantitative data that would help answer RQ1.

Concept Inventory of Natural Selection (CINS). The CINS is used for measuring understanding of natural selection concepts and was developed by Anderson, Fisher, and Norman (2002). It includes twenty multiple choice questions that contain distractors with common alternative conceptions about natural selection and evolution. The questions follow case studies that highlight the basic tenets of evolution, such as the existence of variation within a species. The instrument has been field-tested with over 200 undergraduate biology students, and is considered reliable and valid (Anderson et al., 2002). The authors reported the Kuder-Richardson 20 method to determine reliability and found scores of 0.58 for Section A and 0.64 for Section B, which are acceptable according to the reliability coefficient of 0.60 that is expected of assessments (Anderson et al., 2002) Anderson and her colleagues used principal components analysis (PCA) to test for internal validity and results showed
support within the ten evolutionary concepts. The authors found that the CINS is appropriate for assessing the knowledge of high school students, biology majors and non-biology majors at ethnically diverse institutions (Anderson et al., 2002).

Few comparable research studies have been found that used the entire CINS. For example, Keleman and Rosset (2009) examined undergraduate students’ understanding of natural selection but used only eight of the CINS items in combination with items from several other tests. While Pobiner wrote that the CINS is “probably the most commonly used in studies of evolution understanding” (2016, p. 253), a review of the literature did not uncover other studies that used the entire CINS to measure conceptual understanding of natural selection and evolution. No list of studies that have used the CINS exists (D. Anderson, personal communication, July 17, 2018).

The authors of the CINS divided it into ten categories, each assessing understanding of a biological concept related to evolution. The concepts included were biotic potential (#1, #11), population stability (#3, #12), natural resources (#2, #14), limited survival (#5, #15), variation within a population (#9, #16), variation inheritable (#7, #17), differential survival (#10, #18), change in a population (#4, #13), origin of species (#8, #20), and origin of variation (#6, #19), with each question containing distractors based on typical alternative conceptions for that concept (Anderson et al., 2002).

Measure of Acceptance of the Theory of Evolution (MATE). The MATE was designed by Rutledge and Warden (1999) and contains twenty Likert-scale items that can shed light on students’ agreement or disagreement with various parts of evolution. The MATE has been shown to be robustly reliable and has been field-tested as well (Rutledge & Warden, 1999). Testing the MATE for internal consistency produced a Chronbach alpha of
which demonstrates that the MATE items are related and measure the same construct (Rutledge & Sadler, 2007). Since this study uses undergraduate non-biology majors as its research sample, it is important to note that the MATE has been validated as a measure of evolution acceptance for this demographic (Rutledge & Sadler, 2007). The MATE has twenty questions and uses a Likert scale of 1 (strongly disagree) to 5 (strongly agree), with a score of 3 for neutral. Students can receive up to five points per question. Half of the questions are reverse coded to determine whether students are answering consistently (Rutledge & Sadler, 2007). The total possible score on the MATE is 100 points. A higher MATE score indicates more acceptance of the theory of evolution, while a lower MATE score indicates less acceptance.

The authors of the MATE divided the instrument into six categories, each assessing participants’ acceptance of a specific concept. Items 1, 9, 18, and 19 address the process of evolution. Items 2, 10, 12, 13, 14, and 20 relate to the scientific validity of the theory of evolution. Items 3 and 15 examine acceptance of human evolution. Items 4, 6, 8, and 16 address evidence for evolution. Items 5 and 17 look at the scientific community’s view on evolution, and items 7 and 11 address the age of the Earth (Rutledge & Sadler, 2007).

One criticism of the MATE is that it did not provide an operationalized definition of the term acceptance, which Romine and colleagues believe should include the following dimensions: 1) agreement with the fact that change occurs over time in humans and all other forms of life, and 2) agreement that the evidence of evolution is credible (Romine et al., 2017). Both the CINS and the MATE are used frequently in science education as quantitative tools to learn more about evolution teaching and learning (e.g., Borgerding et al., 2017; Cavallo & McCall, 2008; Ha, Haury, & Nehm, 2012). However, the MATE was used
in this research to assess students’ acceptance of evolution because it allows for comparison with previous studies due to its frequent use in educational research.

**Data collection procedures and security.** Each student in the control and intervention sections took the CINS and the MATE as a pre-assessment the week prior to the evolution unit and as a post-assessment at the end of the semester. Answers were entered into a Google Sheet and scored according to the scoring guides included with the instruments. Data was identified with a number that was assigned to the students at the beginning of the semester so that pre-test and post-test scores could be compared to look for change over time, and so that quantitative data can be connected to interview data without being linked to students’ names.

**Qualitative Data Collection**

Five sources of qualitative data were collected and analyzed in order to answer RQ2. Each data source is described in this sub-section.

**Interviews.** Since all 80 biology students could not be interviewed, students were selected through purposive sampling, choosing students based on their MATE scores. Using a wide variety of students from the classes will allow a larger proportion of this study’s readers to connect with the stories they are reading (Seidman, 2013). In the control group, quantitative data from the MATE was used to recruit a heterogenous group of five people to participate in interviews. For the intervention group, students who have high MATE scores, students with medium MATE scores, and students whose MATE scores are low were chosen as interview participants. Intervention group students were interviewed twice, once before the evolution unit and once after. The intention was to have a diverse group of interview
participants for each class, especially related to their acceptance of evolution. A small financial incentive was given to the interview participants.

The interview questions were created based on previous research on students’ knowledge and understanding of evolution as well as cultural border crossings (Aikenhead & Jegede, 1999; Blackwell, Powell, & Dukes, 2003; Shtulman & Calabi, 2013; Smith, 2010). See Appendix C for interview questions. One example is, “Please compare and contrast what you’ve learned about evolution at school with what you’ve learned about it at home, church, etc. How does what you’ve learned align, and how does it conflict or differ?” and another is “Would you take another class about evolution? Why or why not?” The qualitative data gathered through the interview process will be especially useful to the study of cultural border crossings while learning about evolution, as previous studies have rarely included qualitative data. However, the term “cultural border crossing” was not used until the end of the post-unit interview so as not to predispose the students’ answers.

Interviews were conducted in the community college library at a mutually agreed upon time. Since one of the limitations of interviews as qualitative data sources is possible bias of student answers due to the presence of the researcher (Creswell, 2003), the interview began with questions that would help establish a relationship with the students without the researcher sharing personal views on religion or science. The researcher encouraged students to share by using positive non-verbal cues such as smiling. The interviews were transcribed by hand and kept in files named with students’ pseudonyms on a password protected computer.

Field notes. During the evolution unit in both classes, observations were recorded on a laptop in order to provide descriptive and reflective information (Gall, Gall, & Borg, 2003).
Field notes were taken fairly surreptitiously because other students were also taking notes on their computers. Mr. Gloucester’s and the students’ exact words were documented whenever possible. Observer effects such as student reactions to the researcher’s presence or including personal biases when taking field notes could not be completely avoided (Gall et al., 2003), these effects were minimized by remaining unobtrusive in the classroom and reflecting on field notes. A sample of the field notes is included in Appendix G.

**Evolution autobiographies.** This assignment was given to students before the unit began. As previously discussed, it was modeled after an assignment from previous research (Martin-Hansen, 2008) and was used to assess students’ understanding and acceptance of evolution before the unit began. See Appendix E for this assignment. Students’ evolution autobiographies were submitted their names redacted but the student ID number included so the assignments could be used for data triangulation. Students who did not return informed consent forms submitted the Evolution Autobiographies to Mr. Gloucester, but they were not used as data in this dissertation research.

**Card sort activity photographs.** This data source was designed to collect information about what types of knowledge sources students would examine to answer different sources of questions, thereby looking for collateral learning evidence. Students were assigned the card sort activity as previously described, and cards were sorted on top of their desks. Students wrote their ID numbers for the research on post-it notes and put them alongside the card sort activity, so their desk tops could be photographed for future data triangulation. Students who did not submit the informed consent form were unobtrusively paired together so that IRB was not violated if a student who did not give informed consent chose to pair with a student who had submitted consent. Photographs were temporarily
stored on a password-protected phone and later uploaded to a password-protected drive on a laptop. No photographs contained students’ names or any other identifying information.

**School board scenario assignments.** As previously discussed, these assignments were given to the students during the evolution unit and discussed at the end of the unit. This assignment was included in the intervention in order to assess how students think about science and religion. The students submitted their assignments to Mr. Gloucester, who gave them to the researcher after redacting their names. See Appendix H for a copy of the School Board Scenario assignment.

To summarize, there are two sources of quantitative data (CINS and MATE scores) that will assist in answering RQ1, and five sources of qualitative data (interviews, class session field notes, Evolution Autobiographies, card sort photos, and School Board Scenarios) that will help answer RQ2.

**Data Analysis Methods**

This sub-section explains the data analysis methods used in this dissertation. First, the quantitative methods used to analyze data to answer RQ1 are shared, then the qualitative methods used to analyze data related to RQ2 are described.

**Quantitative Data Analysis Methods**

The first step in answering RQ1 through quantitative analysis is to test whether the scores on the CINS and the MATE are normally distributed. A Shapiro-Wilk normality test was used in StatCrunch to confirm normal distribution of the data. Since the scores were not normally distributed, the Wilcoxon-Mann-Whitney test was used to verify whether results from the control and intervention classes were statistically equivalent and therefore comparable. To compare the pre- and post-unit scores between the control and intervention
classes, a mixed ANOVA was used. These statistical analyses offered the general results to answer RQ1.

The CINS and MATE had previously been tested for construct validity. The MATE’s construct validity was measured through factor analysis which reported one factor with an eigenvalue greater than 1 which conveyed that only one factor was present (Rutledge & Warden, 1999). Construct validity of the CINS was determined by asking a panel of five biology experts to choose the intended answer of each item and subsequently modifying the items as necessary (Anderson et al., 2002). The intervention, interview protocol, and codebook were designed using the cultural border crossing and collateral learning frameworks to ensure the qualitative data measured students’ thoughts and emotions on these two theories.

Qualitative Data Analysis Methods

In order to analyze the data, one must “search through the clues (data) to follow threads of evidence (patterns of consistency in the data) to a final decision” (Hays, 2004, p. 232). RQ2 (How do community college biology students navigate border crossings that might be necessary due to conflicting religious and scientific beliefs using some form of collateral learning?) is the thread of evidence that is followed in this part of the data analysis.

The interviews with students from both biology sections were recorded and transcribed. Each line was numbered within the transcription document so direct quotes can be easily referenced in Chapter Four. Interview data was coded by organizing the interview material into chunks and then ascribing meaning to the chunks (Creswell, 2003). Codes were assigned to each chunk of data in order to offer information about where the chunk belongs within the qualitative data (Tesch, 1990).
Before any coding began, a codebook was created with *a priori* codes generated from the cultural border crossing and collateral learning theoretical frameworks in order to analyze the qualitative data. (See Appendix I for full codebook.) Each code was assigned a definition, taken directly from the literature when possible, and an example was added for each code. The full codebook including *a priori* and emergent codes can be seen in Table 2.
Table 2

Codebook

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>culture (C)</td>
<td>&quot;norms, values, beliefs, expectations, and conventional actions&quot; of a group</td>
<td>We watch a lot of videos about animals in my family. (specifically home culture)</td>
</tr>
<tr>
<td></td>
<td>(Phelan et al 1991, p. 228)</td>
<td></td>
</tr>
<tr>
<td>microculture (MC)</td>
<td>&quot;within every culture there are subgroups or social communities that more</td>
<td>At Environmental Club meetings, we talk about how climate change might affect evolution.</td>
</tr>
<tr>
<td></td>
<td>or less share unique combinations of norms, values, beliefs, expectations,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and conventional actions&quot;</td>
<td></td>
</tr>
<tr>
<td>cultural border</td>
<td>&quot;the transition from a student's life-world into a science classroom is a</td>
<td>What we learn in science class is so different from what I learn about at home.</td>
</tr>
<tr>
<td>crossing (CBC)</td>
<td>cross-cultural experience for most students&quot; (A&amp;J, p. 271)</td>
<td></td>
</tr>
<tr>
<td>smooth cbc (SCBC)</td>
<td>&quot;We do not recognize that a cultural border potentially exists between the</td>
<td>It never occurred to me that some people's beliefs might contradict evolution.</td>
</tr>
<tr>
<td></td>
<td>two microcultures&quot; (A&amp;J, p.272)</td>
<td></td>
</tr>
<tr>
<td>managed cbc (MCBC)</td>
<td>&quot;when we feel a degree of discomfort with another microculture we might be</td>
<td>I don't raise my hand in science class because I'm not sure I believe in all of it.</td>
</tr>
<tr>
<td></td>
<td>unwilling to engage in risk-taking social behavior&quot;</td>
<td></td>
</tr>
<tr>
<td>hazardous cbc (HCBC)</td>
<td>&quot;when our self-esteem is in jeopardy, we tend to react in various ways to</td>
<td>I don't talk in groups because my classmates will think I'm stupid for not believing in evolution.</td>
</tr>
<tr>
<td></td>
<td>protect our egos&quot;</td>
<td></td>
</tr>
<tr>
<td>impossible cbc (ICBC)</td>
<td>&quot;if psychological pain is involved, avoidance is our natural response&quot;</td>
<td>I skipped bio in HS all the time because it was too confusing to think the words of Genesis might</td>
</tr>
<tr>
<td></td>
<td></td>
<td>not be true.</td>
</tr>
<tr>
<td>collateral learning</td>
<td>&quot;constructing scientific concepts side by side and with minimal interference</td>
<td>At school, we talk about hominids, but at home we talk about Adam and Eve.</td>
</tr>
<tr>
<td>(CL)</td>
<td>and interaction with their indigenous concepts related to the same physical</td>
<td></td>
</tr>
<tr>
<td></td>
<td>event&quot; (A&amp;J, p.276)</td>
<td></td>
</tr>
<tr>
<td>parallel collateral</td>
<td>&quot;the conflicting schemata do not interact at all, the compartmentalizing</td>
<td>At school, we talk about hominids, but at home we talk about Adam and Eve.</td>
</tr>
<tr>
<td>learning (PCL)</td>
<td>technique&quot; (A&amp;J, p.278)</td>
<td></td>
</tr>
<tr>
<td>secured collateral</td>
<td>&quot;conflicting schemata consciously interact and the conflict is resolved in</td>
<td>Science and religion are both helpful because they explain things.</td>
</tr>
<tr>
<td>learning (SCL)</td>
<td>some manner&quot; (A&amp;J, p.278)</td>
<td></td>
</tr>
<tr>
<td>dependent collateral</td>
<td>&quot;a schema from one worldview or domain of knowledge challenges another</td>
<td>I think probably God is in charge of how things evolve.</td>
</tr>
<tr>
<td>learning (DCL)</td>
<td>schema from a different worldview, to an extent that permits the student</td>
<td></td>
</tr>
<tr>
<td></td>
<td>to modify an existing schema without radically restructuring the existing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>worldview, students are not usually conscious of the conflicting domains&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(A&amp;J, p. 278)</td>
<td></td>
</tr>
<tr>
<td>simultaneous</td>
<td>&quot;a unique situation in which learning a concept in one culture can facilitate</td>
<td>We learned about how mutations can be beneficial, harmful, or neutral and that day I went home</td>
</tr>
<tr>
<td>collateral learning</td>
<td>the learning of a similar concept in another culture. It does not happen</td>
<td>and watched my blind cat sniff out a mouse before our other cat. It made me realize her mutation</td>
</tr>
<tr>
<td>(SCL)</td>
<td>often and is usually a coincidence&quot; (A&amp;J, p.280).</td>
<td>was beneficial.</td>
</tr>
<tr>
<td>teleology (Tel)</td>
<td>the idea that natural processes are guided by a purpose or goal</td>
<td>They evolved so everyone could survive.</td>
</tr>
</tbody>
</table>

The *a priori* codes created were culture (C), microculture (MC), cultural border crossing (CBC), successful cultural border crossing (SCBC), managed cultural border crossing...
(MCBC), hazardous cultural border crossing (HCBC), impossible cultural border crossing (ICBC), collateral learning (CL), parallel collateral learning (PCL), secured collateral learning (SCL), dependent collateral learning (DCL), and simultaneous collateral learning (SCL).

A PhD candidate who had taken appropriate coursework and had significant research experience served as the second coder and coded 10% of the interview data. The parameters of coding and coding units were discussed before any coding began. Coding units were comprised of each sentence or phrase and double coding one unit was possible. New codes could emerge during coding because the constant comparative method suggests the need for other codes might arise as one is working with the data (Tesch, 1990). The first page of the interview data was coded aloud together using the codebook, then the entire first interview was coded separately. Since the researcher was more familiar with the cultural border crossing and collateral learning theoretical frameworks, the second coder missed some of the coding opportunities on the first pass. For instance, Brandi’s pre-unit interview said, “my mom had a really interesting way of looking at science and evolution in relation to the Bible” (lines 15-16). The researcher used the collateral learning code for this chunk of text and the second coder had not coded this text at all. The researcher explained that this chunk of text illustrates how a person might hold two schemata about the same concept, and the second coder agreed.

The first interview’s codes were discussed, and some additional codes were added that emerged during the initial coding session. Interrater reliability agreement was 85.29%, which means the coding system was reliable (Creswell, 2013). The codes that emerged were: teleology (Tel), general misconceptions (Mis), anthropomorphism (Ant), sources of
knowledge (SOK), personal characteristics (PC), persisting questions (PQ), evidence (E), emotions (Emo), accurate evolution knowledge (AEK), theistic evolution (TE), and nature of science (NOS).

It became clear that sources of knowledge (SOK), personal characteristics (PC), persisting questions (PQ), accurate evolution knowledge (AEK), evidence (E), emotions (Emo), theistic evolution (TE), and the nature of science (NOS) might be important in analyzing the qualitative data for both RQ1 and RQ2. The researcher felt that the teleology (Tel), Anthropomorphism (Ant), accurate evolution knowledge (AEK), evidence (E), nature of science (NOS), and general misconceptions (Mis) codes might be important in later analysis from this research that is beyond the scope of the dissertation. When the second coder had completed 10% of the data and the coders were in high agreement (85.29%), the researcher coded the rest of the interview data.

After coding all the intervention interviews, analysis included connecting threads and patterns to look for themes among the participants. Field notes from the class meetings, photos of the card sorts, Evolution Autobiographies, and School Board Scenario assignments were used to triangulate information found in the interview data analysis. Finally, a narrative approach that discusses the qualitative and quantitative findings in the same document was used (De-Cuir-Gunby & Schutz, 2017). Specifically, the results from each target student were presented using an “extensive description of the [target student] and its context” (Creswell, 2013, p. 237). The findings are summarized in Chapter Five, and conclusions and implications are offered. The goal is for this dissertation to inform educational researchers and science teachers about how we can best teach students about evolution while allowing for a cultural border crossing that, if needed, is as trauma-free as possible.
Trustworthiness

Several methods were taken in order to enhance the study’s trustworthiness. First, a mixed methods approach was designed to expand understanding of how a student’s worldview might affect their understanding and acceptance of evolution by using both quantitative and qualitative data in a single study. In addition, the mixed methods approach allowed findings to be confirmed using both quantitative and qualitative data. However, mixed methods research offers several challenges to researchers. First, data collection needs to be extensive in order to offer accurate information (Creswell, 2003). Administering two previously used and validated instruments (the CINS and the MATE) to control and intervention students both before and after the evolution unit allowed extensive data to be collected.

Threats to Validity in Mixed Methods Research

Internal validity was controlled by ensuring the instruments did not change, gathering data only at the appropriate times, and constructing detailed, scripted lesson plans for Mr. Gloucester to determine the intervention was administered with fidelity. Not all aspects of internal validity could be completely controlled. For instance, the diffusion effect (Creswell, 2003) could have occurred when students talked to each other outside of the classroom.

Threats to external validity can occur when a researcher applies findings to people or settings outside of the study sample (Gall et al., 2003). The findings from this research are designed to be true of these particular students in this specific setting. While they may be somewhat generalizable, the mixed methods aspect of this research inhibits any sort of global generalizability. However, the results of the CINS and MATE can be compared to those of other college-aged students who have previously taken the instruments.
Threats to Reliability in Mixed Methods Research

Reliability was ensured by including the lesson plans, interview protocols, and codebook in the appendices and including a clear audit trail (Gall et al., 2003) that allows others to follow my procedures and methodology. In addition, published instruments that can be used by other researchers were used. Using a second coder to confirm code identification and use also contributed to a reliable study.

Summary

The mixed methods strategy used in this dissertation is designed to answer two research questions. The quantitative data answers RQ1, which examines whether a cultural border crossing intervention affects students’ understanding and acceptance of evolution by examining their MATE and CINS scores. The qualitative data explores students’ reactions to the intervention as well as their thoughts on the differences between scientific and religious epistemological sources. The sample includes non-science majors in control and intervention sections of an introductory biology class at a large community college. Data sources include two instruments, administered before and after the evolution unit, as well as interviews, in-class and homework assignments, and field notes. Chapter Four presents the findings from this research. Quantitative data are presented first to answer RQ1, then qualitative data is offered to answer RQ2.
CHAPTER 4

Findings

In this section, quantitative and qualitative results from this research are shared. The results are organized by research question, beginning with RQ1. Within RQ1, results of the CINS (measuring understanding of evolution) and the MATE (measuring acceptance of evolution) are discussed separately and compared when possible. The data related to RQ1 is quantitative and is analyzed using statistical analyses described in Chapter Three. Within RQ2, each intervention student who was interviewed as an individual target student is discussed and their results are compared across cases in the analysis section of this chapter. Triangulation methods are used to support each case’s findings when possible.

Research Question 1—Changes in understanding and acceptance of evolution

The first research question in this dissertation is: How do community college biology students’ understanding and acceptance of evolution change over time after a pedagogical intervention focused on the cultural border crossing model? The CINS measures students’ understanding of evolution and the MATE measures students’ acceptance of evolution. Comparison of Control and Intervention Scores

First, the control class’s scores were statistically compared with the intervention class’s scores to determine whether the classes were statistically equivalent, and therefore comparable. Next, results from a mixed ANOVA revealed that there was not a significant effect of the intervention on understanding or acceptance of evolution. There was no significant main effect of the intervention on MATE scores, F (1, 54) = .22, p = .64 or on CINS scores, F (1, 54) = .25, p = .62. The next section includes quantitative results from the CINS and MATE.
**CINS results.** The CINS has 20 questions, with each question worth 1 point, totaling twenty possible points. On average, students in the both classes scored less than half of the CINS questions right during the pre-assessment. See Table 3 for scores.

Table 3

*Pre-unit and Post-unit CINS Means and Standard Deviations for Control/Intervention Classes*

<table>
<thead>
<tr>
<th>Class</th>
<th>N</th>
<th>Pre-M</th>
<th>Post-M</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>34</td>
<td>9.13 (3.35)</td>
<td>11.38 (4.80)</td>
<td>0.04*</td>
</tr>
<tr>
<td>Intervention</td>
<td>29</td>
<td>9.12 (3.06)</td>
<td>11.92 (3.70)</td>
<td>0.01*</td>
</tr>
</tbody>
</table>

*p < .05

Overall, the intervention class’s mean CINS score for the pre-unit administration was an 9.12, and the post-unit administration mean was a 11.92. The CINS was originally used on community college students and the mean score of that sample was 10.42 (Anderson et al., 2002). Therefore, the mean CINS scores fall within the general range found in previous research.

**MATE results.** The MATE also has 20 questions, and using a five-point Likert scale, could result in scores ranging from 20 to 100. On average, students (n=34) in the control class scored in the moderate acceptance category (Rutledge & Sadler, 2007) on the MATE during the pre-assessment (M = 71.45, SD = 19.58) and students (n=29) in the intervention class on average scored similarly (M = 72.00, SD = 17.70). See Table 4.
Table 4

*Pre- and Post-unit MATE Means and Standard Deviations for Control/Intervention Classes*

<table>
<thead>
<tr>
<th>Class</th>
<th>N</th>
<th>Pre-M</th>
<th>Post- M</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>34</td>
<td>71.45 (19.58)</td>
<td>77.00 (17.89)</td>
<td>0.25</td>
</tr>
<tr>
<td>Intervention</td>
<td>29</td>
<td>72.00 (17.70)</td>
<td>80.8 (15.18)</td>
<td>0.10</td>
</tr>
</tbody>
</table>

These mean MATE scores seem to fall in line with the mean MATE scores of other college students in the US, which range from 64.9 in Mississippi (Walter, Halverson, & Boyce, 2013) to 85.2 in South Florida (Fowler & Zeidler, 2012).

**Research Question 2—How students navigate cultural borders during evolution unit**

To examine how students cross borders, interviews of target students were analyzed using codes. A description of each student is included. As a result of cross-case analysis, five themes emerged. Each theme is discussed at the end of this section.

Table 5

*Target Students and Corresponding Quantitative Data*

<table>
<thead>
<tr>
<th>Name</th>
<th>CINS pre-unit score</th>
<th>CINS post-unit score</th>
<th>MATE pre-unit score</th>
<th>MATE post-unit score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amy</td>
<td>10</td>
<td>11</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>Carrie</td>
<td>6</td>
<td>7</td>
<td>40</td>
<td>66</td>
</tr>
<tr>
<td>Patterson</td>
<td>6</td>
<td>10</td>
<td>74</td>
<td>100</td>
</tr>
<tr>
<td>George</td>
<td>9</td>
<td>9</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Brandi</td>
<td>5</td>
<td>6</td>
<td>87</td>
<td>82</td>
</tr>
<tr>
<td>Neko</td>
<td>10</td>
<td>17</td>
<td>91</td>
<td>98</td>
</tr>
</tbody>
</table>
The primary data used is from the pre- and post- interviews, but other qualitative data sources are included to corroborate the interview data (Yin, 1998). Codes used for interviews are listed after the quote, with the coded chunk bolded within the quote. While the qualitative data includes plenty of interesting data, only the data that informs RQ2 is presented in order to focus the analysis (Yin, 2003). Related codes are included in italics after direct quotes used within each target student’s description.

Target Students

Each target student is described extensively in this subsection, beginning with the student with the lowest MATE score.

Amy as a very low acceptance, moderate understanding student. Amy began the class with only a religious worldview as an impossible border crosser and after the class was a managed cultural border crosser. See Figure 5 for Amy’s cultural border crossing placement.

Figure 5. Amy-Cultural Border Crossing. Prior to the intervention, Amy was classified as an impossible border crosser based on her religious worldview and her previous experience learning evolution. During the unit, she attempted to assimilate evolution into her previously held worldview but was not able to fully do so. Theoretical framework of cultural border crossing (Aikenhead, 1996).
Amy is a dark-haired, petite, White student with a very religious worldview who sometimes had a furrowed brow when discussing evolution in class. She was happy to be interviewed and chatted easily in the community college’s library. Amy shared that she had taken a career aptitude test that encouraged her to work in Human Resources, so she planned to major in such at a four-year university after completing her Associates Degree. She willingly shared her religious and scientific worldviews. Amy began her first interview by explaining, “I’m not a science person. I don’t like science. I’m not very good at it” (pre-unit interview, lines 13-14), [personal characteristics code]. When asked how she perceived herself in relation to science (in order to examine a possible need for cultural border crossing), she replied, “Well like I said, it’s not very interesting to me, but I am a Christian so a lot of the things I believe can contradict sometimes with the stuff we’re taught in Biology or other science classes” (pre-unit interview, lines 16-17), [impossible border crossing code]. She elaborated on how science is “meticulous” (line 20) and therefore her relationship felt “distant” (line 22), [cultural border crossing code]. When asked about her relationship with evolution, Amy stated:

Um, I mean, personally that’s not something I believe in, and it actually makes me… So when I took Biology in high school, I had a teacher that would basically talk about how foolish Christians were to not believe in evolution to the whole class, so it was basically torture for me. You shouldn’t do that. You should say what you’re supposed to teach, and I can believe what I want to believe (pre-unit interview, lines 29-32). [impossible culture border crossing code].
She added that she was nervous to come into Mr. Gloucester’s classroom because she did not want to repeat that experience. Amy elaborated on this experience in her Evolution Autobiography assignment. She explained:

The teacher that I had [as a high school sophomore in Biology class] was super nice and I liked her a lot, but I didn’t like the way that she taught this subject in particular. She taught evolution as a fact, and made it seem like any other idea that didn’t support evolution was completely foolish and unreasonable. I don’t mind that she thought these things, because most people do. The part of the class that got me upset was that she verbalized these thoughts and made me feel isolated in the classroom. I shouldn’t have to sit through a class and listen to a teacher make fun of my beliefs. A teacher should be able to teach objectively, and she definitely did not… I was angry that they were teaching this in schools because it just further showed how far the world has drawn from God. I wasn’t anxious at all, just pretty angry and annoyed that I had to sit through a lecture every single day and hear the personal thoughts of my teacher. The part of the class that I did like was that I was able to learn more about evolution. I wanted to gain more knowledge on this subject that I was so against. (Evolution Autobiography Assignment, 2018, p. 1-2)

During the interview, Amy was asked to share her views on the relationship between religious explanations for the diversity on Earth such as Noah’s Ark and scientific explanations for the same (to check for the presence of collateral learning), she said:

Well, I feel like first of all, it depends on the religion you follow, because like everyone’s different. But in like the [relationship between religion and science] that I created, the biggest difference that kind of forms the relationship is that I think God
created a man first, and evolution supports the theory that we came from apes. And that type of background, and that family. **But I think that humans were created first, so that can’t be possible.** (pre-unit interview, lines 61-64). [impossible cultural border crossing code]

Prior to the evolution unit, Amy seemed to believe that both science and religion could provide important information about the world. In this answer, she also spoke a little about how she views the Bible as evidence her religion provides to answer questions about life. Amy asserted:

**I think religion explains the very beginning of it.** [source of knowledge code]

There are scientific things that could back up a couple of points [dependent collateral learning code, source of knowledge code], but unless we were there when, like, the Earth was created, we will never know for certain. So like, it being written down, and it says the Bible is inspired by God, which means that He’s going through these people as vessels to write it down. **So it’s written down. And that’s what I find confidence in, is that it’s documented** [source of knowledge code]. Not that you can’t document research, but we’re coming from such a different perspective. The Bible was written so long ago, and the Earth has changed so much, so we have a completely different perspective from the people who lived so long ago. **So that’s what I find confidence in, that it’s way, way before we existed was when the Bible was written, so that’s for me what science can’t explain** [source of knowledge code]. (pre-unit interview, lines 72-80).

Next, Amy was asked whether scientists could be religious to elicit more of her thoughts about holding religious and scientific points of view simultaneously. Amy revealed that she
believed you could hold both lines of evidence, and gave the example of Kent Hovind, whom she described as a biologist who “does really in-depth research, and it actually backs up what the Bible says” [dependent collateral learning code] (pre-unit interview, lines 88-89). Hovind received a doctorate in Christian Education through Patriot University and created “Creation Science Evangelism” which focuses on the Biblical evidence that God made the world in less than a week about 6,000 years ago (Dr. Dino.com, 2018).

In the post-evolution unit interview, Amy shared that she liked the way Mr. Gloucester started the unit. She felt that it was very different from the way her high school teacher taught, especially because Mr. Gloucester “made it very clear that we didn’t evolve from apes, and that’s what most high schoolers are taught unfortunately [misconceptions code]” (post-unit interview, lines 10-11). As a follow-up question, Amy was asked to go more in-depth about the day Mr. Gloucester explained to the class that no scientists believe that humans evolved in a linear fashion from apes as indicated to many by this classic illustration (Howell, 1965), shown in Figure 6.

**Figure 6.** Rudolph Zallinger's "The Road to Homo Sapiens" from Time-Life's 1965 book Early Man

Amy described her feelings during that lecture by saying:
It just made me so surprised and caught off-guard. Not that I was closed off to hearing it, but it made me more… I don’t know, I feel like I had a better understanding of what people were saying about evolution [emotions code]. Whereas before I was like, “No, no” but now I’m like, “Ok, I see what you’re saying. It makes more sense that we didn’t evolve directly from apes.” So that was a little bit more plausible for me, to see why people would believe in that idea [cultural border crossing, dependent collateral learning codes]. (post-unit interview, lines 41-45).

When asked to describe her feelings when generally discussing evolution in class during the unit, Amy explained:

Um, I wasn’t overjoyed by having to learn about it [emotions code], but I was interested to see how it compared to my other class. And me being not overjoyed was because of my previous class. And just like the connotation that comes with that topic, and the way that it’s taught in school [emotions code]. But I was pleasantly surprised with how [Mr. Gloucester] taught it in general. [emotions code] And I think that had a lot to do with the activities in the beginning that brought up other ideas, and so it wasn’t like, “This is the only way that it’s possible” and I just liked that a lot (post-unit interview, lines 34-38). [collateral learning code].

Later in the interview when talking about how evolution was taught during the lab sessions, Amy’s eyes lit up as she shared an instance of collateral learning:

Actually, the day that [Mr. Gloucester] did the lab with the skulls, it made me believe more in God than in evolution [dependent collateral learning code]. Because a lot of it backed up what the Bible says [dependent collateral learning,
Because when Adam and Eve sinned, he said that you’re going to be in a lot of pain in childbirth, so that makes sense. And before Adam and Eve, sinned, there was no death. So we were not made to eat animals; I mean, I don’t think that was the purpose of us. **So when he was talking about the teeth, that they can eat meat, but they’re more made for plants and herbs. So God said that we could eat meat after they sinned, but before that we ate plants, so that made me feel more like the Bible was true** (post-unit interview, lines 52-58). [dependent collateral learning code].

When discussing whether science and religion come into conflict for people when studying evolution, Amy explained that her religious views influence what she does and does not believe about evolution. For instance, she does not accept hominid evolution because that does not appear in the Bible, but after learning about the pelvic bones and teeth in a lab session, she was able to connect attributes of those fossils with what she knows from the Bible, which led to acceptance. Amy agreed that she has very firm religious beliefs and it is difficult for her to accept scientific concepts that contradict those beliefs.

Amy was asked whether she thought some students had to figuratively cross cultural borders between a home environment and a science classroom. She answered:

**Yeah, I do** [cultural border crossing code]. Because I **definitely believe that evolution has become like a cultural thing. Like I think that most people do believe in evolution** [culture code]. Especially in the South, because like the Bible belt, like I’m from NY and I can tell that there’s a lot more Christians down here. **But I would say that as a whole, it’s generally believed that evolution is true, and most people accept that** [culture code]. So I think that people like me who are
Christians would probably feel that way, but for the rest of the people, probably not. Because other religions do go with evolution, and I would say that Christianity and the Bible does not [impossible cultural border crossing code] (post-unit interview, lines 101-106).

Amy’s other qualitative data supports her interview data. In her evolution autobiography, Amy mentioned:

Even as a child in middle school, I knew that these ideas [evolution and the Big Bang Theory] didn’t line up with the creation story of the Bible. I believe that every word of the Bible is inspired by God, meaning that everything in the book is true. So, if the Bible doesn’t support the theory of evolution, then neither do I. (Evolution autobiography, 2018).

As in her interview, Amy did not seem to feel that secured collateral learning could be possible. She also mentioned in the evolution autobiography that her high school teacher had “taught evolution as fact, and made it seem like any other idea that didn’t support evolution was completely foolish and unreasonable” (Evolution autobiography, 2018). While Amy thought focusing on science was typical in a science classroom, she felt upset that the teachers “verbalized these thoughts and made me feel isolated in the classroom” (Evolution autobiography, 2018).

While Amy was engaged during class meetings, triangulation of the field notes offered little supporting evidence to answer RQ2. When discussing creation stories, Mr. Gloucester asked if the Haida (a Northwest Coast tribe) could simultaneously accept their creation story of Raven finding the first men in a clam shell and the scientific theory of evolution. Amy answered that it depended on which part of evolution they were being asked
to accept and elaborated that “if they have to believe in the Raven and the part where we came from apes, then no” (Day two field notes). This quote collaborated Amy’s previous quotes related to collateral learning. The card sort activity results showed that Amy (and her partner, whose evolution acceptance level was roughly twice as high as hers) placed the most questions in the source of knowledge category they called “God”, including questions such as “How are great apes and humans related?” and “How did all lifeforms come to live on Earth?” Her creation of the “God” source of knowledge category and subsequent assignment of the majority of the questions to it supports her interview data regarding the Bible as her most valued source of knowledge and her need for cultural border crossing when learning about evolution. Their other categories, “Scientist” and “The law” had questions very specific to those sources of knowledge. For example, the “Scientist” category included questions like “What is a cell made of?” and “How did the Grand Canyon form?”, and “The law” category had only “Should people be able to own guns for personal use?” Perhaps if the Bible had contained a story specifically explaining how the Grand Canyon was formed, that question would have been placed in the “God” category as well.

**Carrie as a very low acceptance, low understanding student.** Prior to the intervention, Carrie was a managed border crosser. Her movement on the cultural border
crossing framework did not move after the intervention. See Figure 7.

Figure 7. Carrie-Cultural Border Crossing. Prior to the intervention, Carrie was classified as a managed border crosser due to her dual scientific and religious worldviews and the thought she had put into the two. During the unit, she did not achieve secured collateral learning regarding her worldviews and remained in the managed border crossing category. Theoretical framework of cultural border crossing (Aikenhead, 1996).

Carrie is a friendly, blonde, White student with a religious worldview who tends to raise her hand often in class to ask questions. She talked animatedly during our interview in her school’s library but was also quite flustered. Carrie apologized and quietly explained that she suffers from various emotional issues such as anxiety and a memory disorder. During the interview, her thoughts seemed to wander as she would glance around the room, and she quite often interrupted herself. Many of the quotes pulled from her interviews show Carrie often speaks in fragmented sentences. She also uses phrases of uncertainty such as “I think that…”, “I feel like…” and “If that makes sense…” quite often when talking and writing.

While Carrie’s quantitative scores placed her in the same categories as Amy, some of her qualitative data indicates that her worldview is not the same as Amy’s. Both of Carrie’s parents are pharmacists so she grew up in a household with parents who were very interested
in science and have a worldview that includes science and religion. She felt that her relationship with science was very positive. When asked about her relationship with evolution to check for her potential need for assistance with cultural border crossing, Carrie answered:

So evolution, for me, I was born and raised a Christian [personal characteristics code]. And I mean it’s something that I’ve believed my whole life, and it’s something that I’ve never really doubted [personal characteristics code]. Like a lot of Christian people I’ve known who grew up in a religious home say they doubt their faith at some point. Like, I’ve never really had that point, but um, so my relationship with evolution is that I don’t believe in the Big Bang Theory [impossible cultural border crossing code]. But I do obviously believe that if you look at middle schoolers today, they are like so tall. So I believe that bodily changes happen over time. And I believe that animals evolve over time, but I don’t believe in certain parts of evolutionary theory, like if that makes sense [parallel collateral learning code]. (pre-unit interview, lines 22-29).

As Carrie was asked more about her understanding and beliefs about evolution, she became more and more anxious, breathing more rapidly and looking around the room almost frantically while she seemed to rehearse her answer in her head. It was unclear whether she was anxious because she was talking about ideas that might conflict with her stringent religious beliefs or if she was just anxious in general. She was reminded that there were no wrong answers and that the goal of the interview was to explore students’ ideas about evolution, and she explained, “Yes, and actually that’s why I agreed to do this because you seem like a really kind person [emotions code]” (pre-unit interview, line 52).
After that interaction, Carrie took a few deep breaths and settled into her chair more comfortably. We continued the interview and she was asked what she thought the relationship between science and religion is. Carrie said:

I think that they’re really more intermingled than we think. And even between different religions, I think they’re more intermingled than we think. Because I learned this in my high school social studies class, because one religion’s story of Noah’s Ark lined up with Christianity’s story of Noah’s Ark. So there’s a lot of parallels, and I feel like there are a lot more parallels than a lot of people see between science and religion.

Carrie mentioned a video she had seen by Mayim Bialik, the actress who plays Amy Farrah Fowler on “Big Bang Theory” and holds a PhD in neuroscience. Bialik had also supported the idea that there could be commonalities between religion and science and Carrie seemed to think of Bialik as an authority. When asked whether she thought it was beneficial to believe in or use both religious and scientific lines of knowledge when making decisions, Carrie said, “if you focus too much on the minutiae, which science is of course minutiae, I feel like if we focus more on the big picture first and seeing what we agree on, then we [science and religion] can learn from each”

Before the unit, Carrie had many questions about evolution, most of which centered around evidence. She explained:

And I think that the Bible has always made sense to me, because of my sense of faith. But since I don’t have
faith in evolution, it’s harder for me to understand. And I don’t understand necessarily all of the scientific background, if that makes sense. So I think that’s probably a big part of that (pre-unit interview, lines 105-107). [hazardous cultural border crossing code].

Carrie elaborated by saying that when she has a question about religion, she knows she can find the answer in the Bible, but for science (or evolution specifically) there is not just one text she can go to for answers. She said, “…for me, the Bible is older and more established and there are so many more things pointing to it [evidence, source of knowledge codes]. I hope I’m making sense.” (pre-unit interview, lines 122-123).

Carrie’s Evolution Autobiography and school board scenario assignment lent support to her anxiety around the topic of evolution. Her anxiety manifests itself in constantly saying or writing things like, “I think that’s right, but it might not be,” and second-guessing herself. For instance, in her Evolution Autobiography she wrote, “I believe I first heard of evolution at my elementary school. This could be completely wrong, but I think I saw a Bill Nye episode on it when I was in about 2nd grade…” (Evolution Autobiography). On the School Board Scenario, Carrie defined science as “quantifiable, measurable facts that can be tested and proved/disproved” (School Board Scenario) and then later wrote, “*Afterthought=my definition of science is honestly hard to pair with any of these theories, so I tried my best to make a judgement based on the information presented on the next page!” (School Board Scenario). When asked in the school board scenario assignment to explain whether she would vote for Creationism to be added to the science curriculum, she answered, “Based solely upon the reading… I would say yes. I’m pretty sure Creationism is considered a theory… (I’m not sure if this is 100% accurate—I apologize if it’s not!” (School Board
Scenario). Carrie also seemed to be flustered quite often when asking questions in class, often ending them with, “Does that make sense?”

The other qualitative data regarding Carrie supported the idea that she believed some sort of collateral learning was possible between religion and science. She wrote, “The more I’ve learned about both science and Christianity (from church, school, and personal research alike), the more I’ve realized that they’re not really as different as people make them out to be” (Evolution Autobiography). On the School Board Scenario, Carrie voted to teach evolution, Creationism, and Intelligent Design in the science curriculum because she thought, “exposure to various schools of thought may help the students to make connections between theories and realize that maybe we [scientific people and religious people] aren’t so different in opinion after all!” (School Board Scenario).

In the post-unit interview, Carrie began by saying how surprised she was that scientists do not think humans came from apes. She wondered why no one told her that in high school. Besides being very surprised by learning that scientists do not view evolution as a linear process as illustrated in the The Road to Homo Sapiens drawing, Carrie reported that discussing evolution in class did not cause her emotional stress or anxiety. She said:

I see that there are a lot of similarities, and even if things don’t exactly line up, there’s no reason to get mad about people believing different things [emotions code].

Like I believe in the creation of the world by God, but even if people don’t, let’s talk about it and not get angry [emotions code] (post-unit interview, lines 23-25).

She reiterated that she was able to successfully cross the border between her religious background and the science classroom:

The thing is, I feel like now since I’ve taken the class, I have a better understanding.
Like I mean, it didn’t change what I already believed, but I mean I was pretty much already like I can see how these two ideas co-exist, so it’s not like I was gonna get mad about it [collateral learning code]. (post-unit interview, lines 50-52)

When asked in the post-unit interview if scientific views of evolution and her religious beliefs were in conflict, Carrie answered, “I don’t think they’re in direct conflict. I do think there are some disagreements, but I wouldn’t say they were in direct conflict [cultural border crossing code]. That’s a strong term. There’s no reason for people to like hate one another” (post-unit interview, lines 57-59). Carrie alluded to secured collateral learning when asked if she felt her religious and scientific sources of knowledge answered two different types of questions. She answered:

I feel like my faith and my views of science are really in line. Sometimes other people’s perceptions of faith are different, but there’s not direct conflict for me. I answer a lot of questions using my faith. But I feel like my knowledge of each feeds off each other if that makes sense [secured collateral learning, dependent collateral learning codes]. (post-unit interview, lines 66-68)

While the question was designed to elicit thoughts on parallel collateral learning, Carrie seemed to feel like she was able to successfully combine at least some of her religious and scientific views.

The concept of cultural border crossing was explained to Carrie and she was asked if she ever felt she was crossing a cultural border when she entered the science classroom. She replied:

I don’t really feel like that [cultural border crossing code]. Like yeah, not everything said in either place hits me right in the heart, or I would understand
every…but if I completely understood I don’t think I would want to live in it! It
would be very boring. But I can understand how it would be that way for other
people. **I take my religion very seriously, but there’s just no conflict. Like it
doesn’t make me want to cry that I have to go to Biology class now** [successful
cultural border crossing code, emotions code]. (post-unit interview, lines 71-75).

Since Carrie understood that some students might experience cultural border crossing when
attending science class, she was asked how biology could best be taught for people who
experience conflict between their religious and scientific beliefs. Carrie replied that she liked
the activity where they researched creation stories and appreciated that “none of them were
invalidated” (post-unit interview, line 78). She also mentioned that she liked the school
board activity because it allowed for “exposing all three views, like these are just theories”
(post-unit interview, lines 79-80).

**Patterson as a moderate acceptance, moderate understanding student.** Before
the evolution unit, Patterson could be found in a new category of cultural border crossers, the
borderless student. This category is discussed further later in this chapter. He remained in
the borderless category after the unit as well. See Figure 8.
Figure 8. Patterson-Cultural Border Crossing. Prior to the intervention, Patterson was classified as a borderless student due to the fact that he held only a scientific worldview. During the unit, his worldview did not change, and he remained in the borderless student category. Theoretical framework of cultural border crossing (Aikenhead, 1996).

Patterson is a forthright, talkative, Latino student who tended to sit and chat with a group of guys and girls in the back of the classroom. He was initially planning to study engineering, but decided engineering was no longer his career goal after taking Precalculus and decided to do IT instead. He had mainly been taking business courses at the community college in preparation for transferring to a state university. He was taking Biology as a requirement for the university he is planning to transfer to. Patterson said that he does not see himself working in the scientific realm of IT but is open to using computer science skills because he has always been interested in science. He said “even as a little kid, I always wanted to be that mad scientist [personal characteristics code]. Like with evolution, I’ve always been more on that side [cultural border crossing code]” (pre-unit interview, lines 14-15).
Before the evolution unit, Patterson already accepted evolution as the best possible explanation for the diversity of life on Earth. He explained:

From what I’ve read, it doesn’t sound like it’s not possible. You know, I’m very open-minded, and I’ve had this conversation with my parents—my parents are super religious—and I’m like, you know, you can’t really mix religion with reality, you know, science. They don’t mix well [impossible cultural border crossing code].

(Pre-unit interview, lines 42-44)

He said the topic of whether evolution is possible had come up several times with his parents and cousins. Patterson explained in his evolution autobiography that he had grown up going to Catholic church even though he never considered himself “a believer of Catholicism” (Evolution autobiography, 2018). In the pre-unit interview, he talked about a cousin who is very spiritual who he used to talk to about evolution and she would sometimes “hop over between sides [successful cultural border crossing, collateral learning codes]” (Pre-unit interview, line 75) and he would try to change her mind about the validity of religious explanations of life on Earth.

When asked whether science and religion could work together to check for collaborative learning, Patterson responded again that science and religion do not “mix well” [collateral learning code] (Pre-unit interview, line 55). He explained that he is agnostic, but he “likes to be able to see something, to test it out [personal characteristics code]” (line 58). He also said, “Not to demean anyone’s religion, but you don’t really know. But you can know that if you throw a rock out of a window, it’s going to fall down [evidence code]” (Lines 59-60). Patterson thought science can explain physical aspects of the world because they are testable and religion can give people meaning and purpose. He also said
that religion give people “a nice set of morals” (line 62). Patterson’s school board scenario supports his beliefs that religion and science are dissimilar. He voted not to allow Creationism to be part of the science curriculum and said, “Creationism calls for faith while science calls for observation and experiments to prove itself” (School Board Scenario, 2018). Patterson wrote that Intelligent Design also could not be proven through experimentation and relied on faith, which made it different from science.

Patterson was also asked if he believed people could believe in both religion and science, but not combine them, to check for a belief in parallel collateral learning. Patterson answered:

To an extent. I feel like you’re going to get to a point where—you can believe in God, but **you’re going to get to a point where, scientifically, you’re going to be on one side or another** [cultural border crossing code]. I guess when it comes to evolution, you’re going to be on one side or the other [cultural border crossing code] because, I don’t know. I **haven’t read the Bible** [source of knowledge code]. I’m not big on it even though my parents are Catholic, you know. But I **don’t recall anything in the Bible about men evolving from apes, primates, whatever. It’s just God created man** [source of knowledge code], and I **think that when it comes to creation, you can’t…you’re either on one side or the other. You can be evolution and still hold your faith, but I don’t think you can believe in evolution and still believe that man was created in God’s image.** Like in some aspects of science, you don’t really have to choose one side or the other, but there are some **places where you have to be one side or the other** [collateral learning, impossible cultural border crossing codes]. (pre-unit interview, lines 68-73)
So, Patterson thought that secured collateral learning is not possible if one holds a literal interpretation view of the Bible. Patterson’s view on obstacles created by the literal interpretation of the Bible aligns with Barnes and Brownell’s (2018) findings that some barriers, such as a literal interpretation of Genesis, can serve as larger impediments to evolution acceptance.

After the unit, Patterson said he felt “excited” [emotions code] (post-unit interview, line 20) when learning about evolution in the Biology class. During the evolution unit, he had thought a little more about the relationship between science and religion. Patterson explained, “Because the way you believe in science might not be different from the way I believe in religion. Maybe belief is belief, no matter what” [collateral learning code] (post-unit interview, lines 55-56). He felt that evolution could not be taught in a way that did not cause any tension between some students’ religious beliefs and the scientific theory of evolution. He said:

I don’t know how something like what we learned in any science class could be taught wouldn’t conflict with people’s beliefs. I feel like there will always be conflicts. As much as we tiptoe around it, I don’t think there’s any way that it won’t conflict with people’s beliefs. [cultural border crossing code] (post-unit interview, lines 74-76)

Despite this, however, he thought that tiptoeing around evolution was not a good idea. He said, “It’s better that you teach everything regardless of the conflicting interest” [cultural border crossing code] (post-unit interview, line 86). Not teaching evolution would be like “taking out a chapter of a book. Like if you take out the climax of a book, and then you read the conclusion, and you’re like, ‘What happened here?’ It’s like taking out part of
the story” (lines 80-82). While Patterson did not undergo any sort of cultural border crossing during the evolution unit, he felt that some students might go through this sort of process.

George as a moderate acceptance, moderate understanding student. George was in the successful border crossing category at the beginning of the unit and remained there after the intervention. See Figure 9.

Figure 9. George-Cultural Border Crossing. Before the intervention, George was classified as a successful border crosser due to the fact that he believed religious and scientific worldviews were both useful. During the unit, his worldviews did not change, and he remained in the successful border crosser category. Theoretical framework of cultural border crossing (Aikenhead, 1996).

George never spoke during class discussions but was willing to talk about evolution in the interview setting. He’s a tall, athletic, African-American student who works at a boys and girls club-type organization run by a church. He attends the Nazarene church that he works for and while he has a religious worldview, it does not seem to be as strong as Amy’s or Carrie’s. While George was happy to be interviewed and restated and answered the questions in a way that suggested he had previous training on how to respond in interview settings, his answers were shorter than those of the other interview participants.
In the pre-unit interview, he explained that he did not know very much about the evolution, but he thought the concept made sense. While he attends church, he believes that science and religion answer two different types of questions. He explained:

**I think a lot of people would say you have to choose one.** [collateral learning code] **But I think science can tell us how it happened, but it can’t really tell us why.** Well, like in a way, it can’t tell us why [nature of science code]. Like um why we’re able to survive maybe. **It can tell us how these things are changing, but maybe not the reason for it** [nature of science code]. So I don’t think there needs to be like a one, one answer question [collateral learning code]. It has to be-I don’t know. I know for myself, I don’t believe I know everything, so I can’t really say [personal characteristics code]. (pre-unit interview, lines 38-42)

It sounded as if George did not have an issue with crossing cultural borders and that collateral learning of some type is possible. Since science and religion can tell us two different things, there is no reason for them to be in conflict. He elaborated by saying, “Like, I believe in God myself, but I don’t think that has any confliction with science. I think science tells a lot of truth and we can gain a lot of insight from it [collateral learning code]”. (pre-unit interview, lines 45-47).

George was encouraged to think anti-evolutionarily at work, but their indoctrination did not seem to work on him. He explained:

**Well, like at my job, like, we had this Bible study and we watched this video about how evolution is false** [source of knowledge code]. But the reason for that is like to um to explain how the Bible was true. And like so as you can see, it kind of makes it kind of hard to think about [cultural border crossing code]. Yeah, it’s not
It’s like evolution is false, so everything in the Bible has to be true [impossible cultural border crossing code]. So, and I kinda don’t agree with that because I think some people really try to stop an argument for why something can be true without even looking into it [personal characteristics code], so. (pre-unit interview, lines 60-66)

George’s beliefs that both science and religion can offer information about the world demonstrate that he was a likely candidate for successful border crossing even before the evolution unit began.

In the School Board Scenario, George’s opinions aligned with his interview data. He voted that Creationism should not be added to the science curriculum because it is not scientific. In his Evolution Autobiography, George wrote of the video he watched at Bible study at work and explained that he thought “the reason people don’t believe in evolution is because saying it is true is not giving all the credit to their god” (Evolution Autobiography). He elaborated that he believes in god (he used the small “g” for god in his typing) and thinks that evolution is something that “only a higher power can create” (Evolution Autobiography). While the video tried to convince him that science is not reliable, and the Bible should be the only source of knowledge examined to learn about the world, George remained unconvinced. It was unclear what type of collateral learning he was able to do, but he definitely believes that two sources of knowledge can inform us about life. In his card sort, he and his partner, a moderately high accepter of evolution, created two sources of knowledge to answer all the questions—scientists and religion. All the questions dealing with the natural world, such as “When did humans first appear on the Earth?” and “How are great apes and humans related?” were placed in the scientists’ section. Since his partner had a higher level of
acceptance than George, it’s hard to know whether he/she influenced the placement of questions within the categories.

After the evolution unit, George continued to believe that science and religion are not in direct conflict. He explained, “I don’t think they have to conflict [cultural border crossing, collateral learning codes], because I know I don’t know everything [personal characteristics code]” (post-unit interview, line 69). George clarified that he knows lots of different types of people with various beliefs, so it’s “natural” (post-unit interview, lines 73-74) for him to cross cultural borders. When asked whether evolution could be taught in a way that allowed all students to cross cultural borders easily, George said:

I don’t think it’s possible. Cause like if you explain that the Biology of it is facts, their defense is going to be that my belief is facts. I don’t think there’s ever going to not be tension. I think it’s just something you’re going to have to go with.

But for me, I just don’t think that tension will ever go away. [cultural border crossing code] (post-unit interview, lines 77-80).

George’s ability to move easily between religious and scientific settings probably influenced his moderate acceptance of evolution, even before the evolution unit began.

**Brandi as a high acceptance, low understanding student.** Brandi was a successful border crosser before the evolution unit due to the dependent collateral learning that allowed her to hold both scientific and religious worldviews. After the unit, she remained in the successful border crosser category. See Figure 10.
Figure 10. Before the intervention, Brandi was classified as a successful border crosser due to the dependent collateral learning that allowed her to hold both scientific and religious worldviews. During the unit, her worldviews did not change, and she remained in the successful border crosser category. Theoretical framework of cultural border crossing (Aikenhead, 1996).

Brandi was an outspoken student in interviews but was fairly quiet in the classroom. She is a tall, White student with dark red hair who wants to be a social worker/counselor. When asked why she was taking Biology, she answered that she was interested in the body and its link to mental illness. Brandi was the first target student who did not answer that she took Biology because it was required. She grew up in a religious household but was not indoctrinated with a literal interpretation of the Bible. She considers her worldview to be one of science and religion.

Brandi felt that she had “a healthy balance of science and other things” (pre-unit interview, line 16-17). She attributed this to her mom, and explained:

I had religious parents, but my mom had a really interesting way of looking at science and evolution in relation to the Bible [collateral learning code]. So that way I have a healthy balance of science and other things [collateral learning code].
Because like my mom said, the Bible [source of knowledge code] never said...God never said how long a day is. And so when they said God created man in a day, they don’t know how long a day is [dependent collateral learning code] (post-unit interview, lines 15-18).

When asked if she remembered how conversations like the one she mentioned came about, she laughed and said, “There were some times where I was like talking about Barbie dolls and then we end up talking about something else” (pre-unit interview, lines 114-115). Brandi also mentioned conversations like this in her Evolution Autobiography. She said that when she first learned about evolution in 6th grade, it contradicted what she had learned about how living things came to be using the stories of Adam and Eve, and Noah’s ark from church. Brandi explained, “…school and church offered vastly different explanations as to how this world came to be, which gave me anxiety because I did not know who to believe. But my parents evened out those two points-of-view for me” (Evolution Autobiography).

Brandi explained that there are many different perspectives people can take on the Bible, which leads to people using it as a source of information differently. When asked to describe how people can view the Bible differently, she gave the following example:

Like how we’re all taught to believe that we’re all God’s children, and we should all love each other, and we’re all made from Adam and Eve, but like there’s still people who judge another person and have hatred toward another person, for reasons like if you lay with another man it’s a sin. I feel like that’s a good example. I feel like people preach about loving each other, but like not you, because the Bible says I can’t. (pre-unit interview, lines 59-64).
Brandi also explained that science and religion are different. She said that science is more “down pat” [nature of science code] (pre-unit interview, line 77) and “science is something you can see” [nature of science code] (pre-unit interview, line 78) while religion is more of a “belief system” (pre-unit interview, line 81). Brandi feels “I feel it’s beneficial for me because it allows me to look at every perspective. It’s not a narrow mindset. [collateral learning, cultural border crossing codes] It’s kind of like a unique way of looking at it, I guess” (pre-unit interview, lines 87-88). While Brandi did not specific discuss cultural border crossing, it seems that she had the ability to use collateral learning of some sort to consider herself religious and scientific.

Brandi attended an arts-focused school for high school and explained that she did not remember much about any previous formal instruction about evolution. After the evolution unit in Mr. Gloucester’s class, Brandi reported that she felt “indifferent” [emotions code] (post-unit interview, line 17) and that she thought, “Ok, so this is the hard evidence” [evidence code] (post-unit interview, line 17). When asked whether her religious beliefs and what she learned in science class were in direct conflict, she responded:

I think they can both be equally balanced [collateral learning code]. So like if you look at Mayim Bialik, she has a PhD but she’s also really religious in her religion of Judaism. And she talks about being a person of science but also finding balance between the two [collateral learning code] I don’t think it’s really as hard as people think; I just think people have to open their minds a little bit more. Because if you think, if you believe in one or the other, it’s fairly narrow, but there’s still room to openly accept both [parallel collateral learning or secured collateral learning codes]. (post-unit interview, lines 58-62)
She also explained that she did not feel a need for cultural border crossing between her home and the science classroom, but she understood how other people might. Brandi elaborated, saying, “Like if your parents are right-wing conservatives, and your science teacher is like, ‘Technically, that’s not actually true.’” (post-unit interview, lines 66-67).

Brandi thought the best way to change someone’s viewpoint is to confront them with evidence. She said that if someone had a belief, but did not have facts, then they should be given the facts. She also said, “you have to educate, not belittle. Just like say, ‘Actually, there’s the evidence.’ Instead of, ‘You’re being a butthole right now. Here’s why you need…’” (collateral learning code)” (post-unit interview, lines 98-99). Brandi shared an example of when someone had been unkind during a class in high school:

Yeah, and like in high school, in Bio class, there was a super religious girl, who openly spoke up and said, “That’s not what people in my religion believe. Just like we don’t believe in her!” and then pointed at this girl on the LGBT spectrum. And it actually ended up that it was embarrassing this other individual, and I was like, “There’s a right way and a wrong way to do things.” (post-unit interview, lines 102-105).

So according to Brandi, if a teacher wanted to change someone’s line of thinking about something, it should be done directly, but in a kind manner. While she did not specifically say that she disliked the intervention, as a student who was not in need of assistance to cross a cultural border between religious and scientific worldviews, she advocated for direct conversations about the relationship between science and religion.

**Neko as a very high acceptance, moderate understanding student.** Neko was also a borderless student before and after the evolution unit. See Figure 11.
Neko is a short, talkative student of Latina origin with short hair and glasses. She spoke up sometimes in class and was quite talkative and open in the interview sessions. Within the first few minutes of the interview, Neko shared that she wanted to be scientifically literate. This was a different beginning than the other participants’ interviews, as they had all immediately explained that they were not very good at science. Neko also explained that she is an atheist and she thought the debate about evolution between Bill Nye and Ken Ham was “more religiously motivated, and more aimed toward proselytizing than trying to apply an understanding of natural processes” (lines 19-21). From the start, Neko had different opinions about evolution, which triangulated with her high score on the pre-unit MATE.

Her Evolution Autobiography included some information she did not disclose in her interviews. In her autobiography, she said:
I was more religious back three years ago so it puzzled me how evolution fit in with God. I drew the conclusion that God created the universe and earth and evolution took care of things from there. I no longer believe in God, so it doesn’t matter to me anymore. My family thinks evolution is absurd and that scientists “are trying to find ways to deny God”. I have a close friend who thinks that scientists are part of some conspiracy to erase God and he’s a young earth creationist and a flat earther. It is interesting, to say the least. (Evolution Autobiography)

Sharing this information during the interview would have led to more follow-up questions but this source was not accessed until after the interview.

Neko also believes that scientific and religious accounts of the variety of life on Earth cannot be reconciled except in certain cases. She explained:

It’s not gonna work. I feel like it’s wishful thinking to think that, unless you’re one of those evolution theists, you like God sparked it and promptly screwed off, you know like deists or something. I find deists a little more plausible because I think if God exists, he just really doesn’t care [collateral learning code] (lines 49-51).

She further clarified that science can explain natural phenomena and religion can tell you more about what the purpose of life is. She said it “provide[s] comfort for some people” (line 63). Her School Board Scenario answers also demonstrated her belief that science and religion are diametrically opposed. She argued:

It is flat out ridiculous to teach Creationism when so much of the theory denies already proven modern-day physics and chemistry and denies plate tectonic theory. It
is absurd to even consider a theory out of a holy book already rife with historical inaccuracies. (School Board Scenario)

While she did not specifically mention that students with religious beliefs might experience tension when learning about the theory of evolution, it seems that she would think that these students would need assistance crossing that cultural border.

Neko’s lack of religious beliefs did not prevent her from having questions about evolution, and specifically how evolution led to human’s presence on Earth. She commented:

- **It does kind of puzzle me how we could arise from bacterial microorganisms**
  [persisting questions code]. But **if it’s been proven through constant research and peer review** [nature of science code] and you know, **who am I to really, um, doubt** [personal characteristics code]. I’m not saying that it’s the truth, but like, **they’ve verified this. Through like countless tests so…** [nature of science code] (lines 97-99).

Neko said this evidence is enough for her to believe that evolution is the most plausible explanation. This corresponds with Neko’s School Board Scenario assignment, in which she defined science as “the systematic knowledge of the physical and natural world gained through observation and experimentation” (School Board Scenario).

Neko did not experience any sort of anxiety in class when talking about evolution, which is not surprising considering no cultural border crossing was necessary for her. She seemed more worried for the professor rather than for other students and explained, “I just hope there’s no wise guy who thinks he knows more than the teacher” (line 16). Even after the evolution unit and the intervention focused on cultural border crossing and collateral
learning, Neko still felt that religion and science were “contradictory [cultural border crossing code]” (line 44). Neko seemed to think that parallel collateral learning was possible for religious people when learning about science. She said:

Religion is more for what’s the meaning of life. Science doesn’t really provide an answer for that, nor does it have to, you know? It’s an entirely different philosophy, so I don’t think it’s the responsibility of science to answer that, and I don’t think people should blame science for NOT answering that [nature of science code]. Because I think I’ve seen that so many times…like creationism says science doesn’t give you a purpose. But science doesn’t have to give you a purpose. It’s a common misconception. (lines 47-51).

Neko may have understood how others experience cultural border crossing because she crossed a border when she went home, as her parents were only educated through middle school and do not believe in evolution. She said when she is at home, “I don’t talk to them about it. I want to avoid conflict of that type, and I’m just done with arguing. I just want to live in peace. And at home has been better since [personal characteristic, emotions codes]” (lines 58-59). Again, while Neko did not have to cross a cultural border into the science classroom during this study, she recognized that others might need to. She explained:

I do like what Mr. [Gloucester] did. He opened us to many creation myths and what other people believe [collateral learning code]. I don’t think he was ever very pushy. He was just like, this is a scientific belief and feel free to believe whatever you want. I feel like creationists were probably happy with that. They got the grade, and this is a requirement. (lines 61-64).
Like Patterson, Neko felt that successful cultural border crossing might need facilitation for some people, even if she did not need any sort of assistance when learning about evolution.

Cross-Case Analysis

In this section, five themes that emerged from this research are elaborated upon. Themes will be connected to previous research and theoretical frameworks.

Others as Cultural Border Crossing Facilitators

Aikenhead and Jegede discussed how biology educators may need to serve as facilitators for students who need to cross cultural borders in order to understand and accept the culture of science as valid. However, this data illuminates the fact that others might also be responsible for facilitating cultural border crossing.

Three of the students (Amy, Carrie, and Brandi) mentioned figures who influenced their thinking about the relationship between science and religion. Brandi used Mayim Bialik, an actress who is best known for her work in the TV show “Big Bang Theory” and is also a neuroscientist, as an example of someone who “has a PhD but she’s also really religious in her religion of Judaism. And she talks about being a person of science but also finding balance between the two” (post-unit interview, lines 58-60). Brandi saw Bialik as an example of a person who exemplified secured collateral learning. Bialik is a well-known TV figure who is often discussed as an example of how scientists are portrayed in popular culture (Weitekamp, 2015).

Carrie also used Mayim Bialik to illustrate the concept of collateral learning. In the pre-interview, she said:

Mayim Bialik, she’s Jewish and actually has a blog-type thing because she’s actually a scientist. She was describing her relationship because a lot of people come to her
and say how could you be a person of faith, and like be a scientist? And she’s like, there are more parallels than you think. And it’s interesting because obviously, like her being Jewish, she doesn’t believe in a lot of the typical things that scientists think. Her points were very interesting and very valid. I feel like a lot of people make science a religion (sic) or political issues. I feel like there are a lot of differences, but I feel like there are a lot more commonalities than we realize. (lines 65-71).

Bialik’s public discussions (probably mostly online) about her collateral learning served as a way to facilitate some sort of collateral learning for religious students learning about evolution. It is difficult to determine whether Bialik’s collateral learning is parallel, dependent, or secured.

Popular culture was also discussed in relation to evolution, but not specifically tied to cultural border crossing or collateral learning. For instance, Brandi also mentioned actor Tim Allen, famous for playing the lead role in the tv show “Home Improvement,” discussing his tweet that asked why there were still apes on the Earth if evolution is real (pre-interview, line 129). Carrie discussed a new documentary hosted by Katie Couric that made her ponder how not every Christian held the same beliefs about the Bible (pre-unit interview). George referenced the television show “The Walking Dead” when discussing how organisms might need to change if the environment changed (post-unit interview). Neko talked about the Bill Nye-Ken Ham debate on evolution which was widely discussed on social media (Miller, 2014).

From the results of this research, it is clear that students think about evolution and the relationship between religion and science due to popular culture’s coverage of those topics. Perhaps Aikenhead and Jegede did not consider the influence of popular culture on cultural
border crossing and collateral learning during the decades in which they published.

However, results from this research indicate that popular culture can be a factor in students’ understanding and acceptance of evolution. Pop culture figures such as Mayim Bialik are situated within the home culture of students as most students seem to access the views of these figures through social media, not in the context of the classroom. While previous research (Winslow, Staver, & Scharmann, 2011) has shown that parents heavily influence students’ thinking about the relationship between religious worldviews and evolution, this research demonstrates others outside the family and peer groups also influence students’ thinking.

The Road to Homo Sapiens Illustration as an Obstacle

As previously mentioned, there was an audible gasp in the classroom when Mr. Gloucester said that no scientists believe that humans evolved from apes the way the process was portrayed in the illustration. Several students in the class asked, “Why didn’t anyone ever tell us this?” Three of the six target students, including the two with the lowest pre-unit acceptance scores, mentioned The Road to Homo Sapiens in their post-unit interviews. In addition, Brandi mentioned Tim Allen’s tweet regarding our descent from apes, which is related to The Road to Homo Sapiens illustration, in both her pre- and post-unit interviews. The theme of this illustration as a memorable part of the intervention unit was apparent in half of the interviews.

Amy was the target student with the lowest MATE score in both the pre-unit and post-unit administrations. When asked how the evolution unit had been different from what Amy had been taught in high school, she reported, “I don’t think there were very many similarities. A huge part of that was because like you guys made it very clear that we didn’t
evolve from apes, and that’s what most high schoolers learn, unfortunately” (lines 9-11). Later in the interview, Amy explained that when Mr. Gloucester talked about The Road to Homo Sapiens illustration in class:

   It just made me so surprised and caught off-guard. Not that I was closed off to hearing it, but it made me more…I don’t know, I feel like I had a better understanding of what people were saying about evolution. Whereas before I was like, ‘No, no’ but now I’m like, ‘Ok, I see what you’re saying. It makes more sense that we didn’t evolve directly from apes.’ So that was a little bit more plausible for me, to see why people would believe in that idea. (post-unit interview, lines 41-45).

Clearly, learning that The Road to Homo Sapiens was not an accurate representation for human evolution helped open Amy’s mind to an improved understanding of evolution. This relates to previous research by Abraham and colleagues that “evolutionary theory is one of the few areas of science in which there is both wide-scale rejection on and acceptance based on nonscientific concerns” (Abraham et al., 2012, p. 153). While The Road to Homo Sapiens illustration is not of “nonscientific concern”, it is a misrepresentation of the process of hominid evolution that is often discussed in nonscientific forums.

   As another religious student with a low MATE score before the intervention, Carrie also mentioned the class discussion of The Road to Homo Sapiens as information that surprised her. She explained:

   One thing I heard about [in BIO 110] that they didn’t stress in high school is that humans don’t come from apes. So like even in high school, they didn’t stress that. And when you and Mr. [Gloucester] were like, “Nobody thinks that,” I was like
“Why didn’t anybody say that!?!?” This is weird. And the weird thing is that nobody would ever just say that it’s not what evolution means. (lines 18-21)

Like Amy, Carrie was clearly surprised to find out The Road to Homo Sapiens illustration was not scientifically accurate. When she asked, “Why didn’t anyone say that!?!?” (line 20), she threw her hands up in the air with an exasperated look on her face. Amy and Carrie might have been more open to evolution as a valid scientific explanation earlier in their education had The Road to Homo Sapiens not been an obstacle to their acceptance of evolution. Carrie’s MATE score increased by 60.6% after the unit, while Amy’s only increased by one point. Both students’ CINS scores only increased by one point. Yet both mentioned The Road to Homo Sapiens in their post-unit interviews as an illustration they were surprised and relieved to hear was not considered a valid path to modern humans by scientists.

Patterson showed moderate acceptance of evolution before the unit began (MATE score = 74,), and The Road to Homo Sapiens was not an obstacle for him. However, when asked in the post-unit interview how Mr. Gloucester started the evolution unit (to see what target students remembered about the intervention), Patterson answered, “It was a long time ago, but I think I remember that he started with the basic picture of the ape turning into man. He specified that that photo was completely wrong, as in we share a common ancestor, but we didn’t evolve from an ape” (lines 3-5). Patterson, as an atheist, was affected enough by the dismissal of The Road to Homo Sapiens as a scientifically accurate illustration of human evolution to mistakenly believe that it was the first thing Mr. Gloucester discussed in the evolution unit.
While the original artist of The Road to Homo Sapiens “didn’t intend to reduce the evolution of man to a linear sequence… it was read that way by viewers. ... The graphic overwhelmed the text. It was so powerful and emotional” (Barringuer, 2006, p.1), it is often a source of confusion as seen in the meme found in Figure 12.

Figure 12. Creationist meme. An often-seen meme aimed at Creationists who dispute hominid evolution. Used with Creative Commons License permission from “Debunking a creationist meme on human evolution” by K. Gilmore, 2015, from Evolutionary Creationism: A Christadelphian Perspective [blog post].

Two of the three Creationists who were interviewed as target students mentioned this illustration and several students discussed their surprise when they found that believing in this issue was not a requirement for accepting evolution as the process that led to modern humans. This theme was surprising to Mr. Gloucester, and future research on students’
thoughts on this illustration and how it contributes to their worldview on evolution is planned.

Affective Reactions Related to Cultural Borders

As previously discussed, previous research has been found showing that students with religious worldviews can feel defensive when being asked to learn about evolution (Hanley et al., 2014). Students discussing affective reactions to evolution is a theme that emerged in the qualitative data associated with my dissertation research. The words “angry,” “interested,” “mad,” “torture,” “conflict,” “indifferent,” “pleasantly surprised,” “excited,” and “arguing” were seen coded as emotions in the qualitative data. Affective reactions were a theme when discussing cultural border crossing related to evolution.

Some of the affective reactions were negative. For example, Amy explained that in her high school biology class in New York, her teacher frequently talked about how Christians were absurd to not accept evolution. Amy called this class “torture” (pre-interview, line 31) because her teacher’s perspective on Christians applied to Amy’s own personal worldview. Neko described how her worldview on evolution differed from that of her parents, and said, “I don’t talk to them about it. I want to avoid conflict of that type, and I’m just done with arguing. I just want to live in peace. And home has been better since” (post-interview, lines 58-59). Brandi felt like her worldview that valued both science and education allowed her to function easily during the evolution, but she seemed to understand that others might find it difficult when she said, “Like it doesn’t make me want to cry that I have to go to Biology class now” (post-unit interview, line 75). These examples show that negative emotions existed in the classroom and at home when a gulf existed between the home culture and the culture of the science classroom related to evolution. This theme
relates to previous research showing that instructors often created an environment in Biology
classes which students perceived to be unwelcome to their worldviews (Barnes et al., 2017).

Brandi also discussed negative emotions related to differing worldviews in the
classroom and at home. She felt it was important for teachers to “educate, not belittle” (post-
interview, line 98) and elaborated by saying, “Just like say, ‘Actually, there’s the evidence.’
Instead of, ‘You’re being a butthole right now. Here’s why you need…’” (lines 98-99). In
addition, Brandi shared a long story about her Dad, who “tends to say certain things that are
not scientifically correct” (post-interview, lines 82-83). After arguing with her dad about
whether Trump’s health care plan would cover her medical conditions of depression and
anxiety, she emphasized scientific research and “he finally shut up” (line 94). To Brandi,
discussing science with those who did not share her worldview led to negative emotions.

Interestingly, Neko, who has only a scientific worldview, also used negative
adjectives when discussing worldviews that opposed evolution. When she cast her vote in
the School Board Scenario assignment against allowing Creationism to be added to the
science curriculum, she said it was “flat out ridiculous” (School Board Scenario, 2018) to
teach a theory that denies science in a science classroom. She also said it was “absurd” to
consider Creationism, which was “rife with historical inaccuracies” (School Board Scenario,
2018), should be included in the science curriculum of a public school. While Neko did not
feel negatively about learning evolution, she seemed to have a negative opinion of those who
did. Conversely, Brandi seemed to recognize that others might think that some people
thought holding only one worldview, a religious one, was possible, but said that, “there’s no
reason for people to like hate one another” (post-unit interview, line 78). Both of these
students’ comments showed that negativity is perceived to exist on both sides of the cultural border.

Not all affective reactions were negative. Patterson mentioned that he was excited to learn about evolution in the pre-unit interview. In the post-unit interview, Brandi said she had felt indifferent during the unit. After sharing negative affective experiences in the pre-unit interview, Amy mentioned in the post-unit interview that she was “pleasantly surprised” (lines 35-36) during the evolution unit. Whether positive, negative, or neutral, discussing evolution in the classroom and at home led to various affective reactions among the target students.

Borderless Students as a New Category

While the cultural border crossing framework and its cognitive explanation, collateral learning, applied to most of the target students, it seems that another category of border crosser is needed. Aikenhead (1996) discussed four types of border crossers: impossible, hazardous, managed, and successful. However, the interviews illuminated another type of border crosser, as seen in Patterson, Neko, and Brandi. These students had no borders between their home and science classroom cultures. However, they are not exactly successful border crossers, as they did not actually cross any sort of cultural border into the science classroom, because none existed. Patterson, Neko, and Brandi comprise a new category in Aikenhead’s cultural border crossing theoretical framework of students: the borderless students. Students like this do not need anyone to facilitate a border crossing because they have already crossed the border, or never had one. The binary nature of being borderless is obligatory because two types of students fall into this category. Neko and Patterson seem to have crossed borders already in their lives, by adopting a fully scientific
worldview after being raised by religious parents. Brandi, on the other hand, seems to have
had a dualistic worldview from the beginning since she was raised by parents who held both
scientific and religious worldviews.

How Students Think about Sources of Knowledge

The last theme to emerge from this research relates to how students think about the
different sources of knowledge they draw upon to answer questions related to how the
diversity of life on Earth occurred. Several students mentioned factors that led to their
acceptance or lack of acceptance about science or religion as a source of knowledge. There
was no general opinion of science or religion; instead, the students’ opinions on the validity
of science and religion as sources of knowledge varied widely among the target students.
However, some similarities between how students think about their preferred source of
knowledge emerged during the interviews.

First, Neko and Carrie, while holding very different worldviews about religion and
science, remarked on their sources of knowledge in a similar manner. In the pre-unit
interview, Carrie was asked to explain how the diversity of frogs that live in Costa Rica came
about. She answered that she did not know and elaborated “I think that’s one of things that
strengthens my faith, because like my human brain just can’t comprehend. I mean obviously
there’s some kind of explanation somewhere, but I personally don’t know. I’m a mere
human…I don’t understand” (lines 34-36). This comment stood out during the interview,
because in the previous interview that day, Neko had remarked that the evolution of life from
bacteria had been “proven through constant research and peer review and you know, who am
I to really, um, doubt?” (pre-unit interview, lines 97-98). These comments regarding an
average person’s inability to comprehend religion or empirical evidence occurred so
proximately that it was obvious that Neko and Carrie were appealing to authority for answers to questions about life, albeit from two very different authorities.

In addition, Carrie and Amy held similar religious worldviews and characterized science similarly as a source of knowledge. Carrie made a comment about focusing too much on the “minutiae” (pre-interview, line 76) that is science and Amy remarked on the “meticulous” (pre-interview, line 20) aspect of science. These two comments seem to portray science as a source of knowledge based on precision and attention to detail. While the Bible offers many details on Christianity and the history of Jesus, it also shares the big picture of the Christian worldview. The comments made by Carrie and Amy led to curiosity related to whether the two target students do not see the big picture of science and are weighed down by the details about individual scientific concepts.

Codes related to emotions or personal characteristics aligned with Billingsley’s findings (2004) that multiple factors determined students’ epistemological commitments about evolution. Two students in his study of 40 Australian undergraduates had mentioned personality characteristics such as “I’m an imaginative kind of person; I’m not someone who cares if it’s wrong or right” (p. 251) and “I am seeking a view that makes me happy” (p. 251). Personal characteristics also appeared in target students’ explanations about evolution acceptance. For example, Brandi explained that she was “the type to ask a lot of questions. But sometimes it wouldn’t exactly be a question, it would just lead into a conversation” (pre-unit interview, lines 118-119). George said that he did not think every question had one answer because, “I know for myself, I don’t believe I know everything” (pre-unit interview, line 42). After self-identifying as “not a science person” (pre-unit interview, line 13) at the
very beginning of the interview, Amy expounded that because she did not love science, “if you don’t have a passion for it, you can just kind of zone out” (pre-unit interview, line 21).

Like Amy, Carrie self-identified as a non-science major at the beginning of the interview, saying, “I’m a real English-y person” (pre-unit interview, line 6). Several instances of the personal characteristics code were found in Carrie’s pre-interview, where she shared personal characteristics like being a Christian, being uncomfortable asking questions in class due to her ADD and anxiety, being religious, etc. Neko shared personal characteristics such as liking the paranormal and believing in ghosts, saying, “It’s not very scientific, but it’s interesting” (pre-unit interview, line 22). Patterson also shared personal characteristics related to his religious background, describing himself as agnostic. All six target students discussed personal characteristics in their interviews, and frequently used these characteristics to paint broad pictures of their relationships with science rather than discussing features of their personalities only when related to acceptance of evolution.

This study supports the usefulness of qualitative data in describing learners’ thoughts and feelings when scientific and religious worldviews conflict while studying evolution. From this study, one can see that a wide variety of epistemological positions on the relationship between science and religion exist in this community college biology classroom. Educators need to know about the variety that exists within their classrooms in order for compassionate and thoughtful education to occur. Jegede and Aikenhead (1999) believed that teachers might benefit from acting as “cultural brokers” to help facilitate cultural border crossing among their students. Extending this tourism metaphor, when traveling with a guide to learn about another culture, it is often true that both the guide and the tourist learn from each other. Many times, the guide might ask the tourist questions about his culture,
investigating what they have previously heard about the tourist’s home culture. In addition, the guide shares information about the place on which she is an expert, expanding the tourist’s mind about places he may not have visited before. It is helpful to think of a science classroom as a foreign destination for some students. While the educator is serving as the guide, without conversation with the tourist (the student), not only does the guide miss the chance to learn from the student, but also the student may not gain a full understanding of the new culture. For cultural border crossing progress to be made, it is beneficial for objective, non-judgmental conversations to occur between the tourist and the guide. The cultural border crossing intervention used in this study allowed for these conversations to occur in the classroom and corresponds with previous research that pedagogical practices can reduce the perceived conflict between science and religion (Barnes & Brownell, 2018) which can lead to more successful collateral learning and cultural border crossing.

Summary

In this chapter, quantitative results of the instruments that measured understanding and acceptance of evolution by students in the control and intervention sections of BIO 110 were presented. The pre-unit scores of the control and intervention sections were statistically similar enough to validly offer a comparison between students in the two sections. Analysis using mixed ANOVA showed that there was no statistically significant effect of the intervention on students’ understanding and acceptance of evolution.

The qualitative data was presented using descriptive methodology. Six target students from the intervention section were described, using participants with a range of MATE scores. The experiences of these target students were examined through interview data, with triangulation accomplished through data from field notes and other assignments.
Codes from the interviews were used to demonstrate how the data were analyzed. Patterns found in the qualitative data were discussed and related to the previous research examined in the literature review.

In the final chapter, practical and theoretical implications of this research are offered, suggestions for future research are made, and the contributions this research has made to the field of science education are acknowledged.
CHAPTER 5

Discussion

This chapter provides summaries of findings regarding both research questions. It also highlights findings regarding each research question and interprets them using relevant literature. Recommendations for pedagogical practice based on the findings as well as recommendations for future research on this topic and the theoretical framework of cultural border crossing are both offered.

Overview of Research

The purpose of the research study was to examine how a pedagogical intervention based on the cultural border crossing and collateral learning frameworks affected students’ understanding and acceptance of evolution and their abilities to manage tension that might occur as a result of the collision between scientific and religious worldviews. There were two research questions: RQ1) How do community college biology students’ understandings and acceptance of evolution change over time after a pedagogical intervention focused on the cultural border crossing model? and RQ2) How do community college biology students navigate border crossings that might be necessary due to conflicting religious and scientific beliefs using some form of collateral learning? By comparing gains in control and intervention classes, it is clear that while there were slight increases in the mean scores on the MATE and CINS after the intervention, the intervention did not affect students’ understanding and acceptance of evolution in a statistically significant manner. Qualitatively, the interview data revealed that students reflected positively on the intervention. The experiences with cultural border crossing and collateral learning varied
widely between the six interview participants. Analysis and synthesis of the findings are included below, along with conclusions and recommendations based on the findings.

This research is novel because college biology instructors rarely discuss religion during an evolution unit and very few instructors know whether their students accept evolution as a valid scientific theory (Barnes & Brownell, 2016). In addition, Mr. Gloucester discussed religion as a source of knowledge, albeit not one that offers testable hypotheses about natural processes. This type of discussion distinguishes Mr. Gloucester from other professors who have discussed religion in a very shallow manner or spoken out against religion during their evolution units, saying things like “If you believe in creationism, you can’t believe in any of the foundations of science and that will destroy America. You will destroy America.” (Barnes & Brownell, 2016, p. 11). While there are several other studies that examine the perspectives of college biology instructors while teaching evolution (Barnes & Brownell, 2016; Rice, Clough, Olson, Adams, & Colbert, 2015; Wilbur & Withers, 2015), none include a mixed methods design based on an intervention with data from intervention and control groups. Therefore, the analysis and conclusions described below offer important, novel research to the body of literature on evolution teaching and learning.

**Summary of Quantitative Findings**

While the mean MATE and CINS scores exhibited gains after the evolution unit, the intervention did not have a statistically significant result. The study was likely underpowered due to the small sample size. In addition, the variance in MATE and CINS scores within the sample influenced the lack of main effect.

**Acceptance of evolution.** Students’ scores on the MATE varied widely in both pre-intervention and post-intervention administrations. Students who were the least accepting of
evolution generally moved from low to at least medium acceptance after the intervention. The mean MATE score rose by 8.8 points, and only two students (8.3% of the sample) remained in the “low acceptance” or “very low acceptance” as compared to eight students (33.3%) who were in these categories before the intervention. In the control group, the initial percentage of students in the two lowest categories of acceptance was similar at the beginning of the evolution unit (32%), and only dropped to 25% after the unit. This suggests that while the effect of the intervention was not statistically significant, students who were less accepting of evolution before the unit moved into more accepting categories afterwards. Students who were initially less accepting of evolution may have held strictly religious worldviews or may not have held firm opinions on evolution, as they were non-science majors. Students who did not hold firm opinions on evolution before taking a course in it have been shown to increase acceptance in previous research (Ingram & Nelson, 2006). Students in this study who were already impossible border crossers or possessed strictly compartmentalized parallel collateral learning in regard to religious and scientific worldviews were probably most likely not to increase their acceptance of evolution, which corresponds with results from previous research (Wiles & Alters, 2011).

In light of previous research, the mean increase in MATE scores may also be explained by an increase in their maturity level and the development of their epistemological commitments. College students typically begin college with more black-and-white, dichotomous epistemological ideas (Perry, 1970) and instruction based on knowledge of undergraduates’ epistemological development is needed for successful evolution instruction (Borgerding et al., 2017). It is possible that the discussions of sources of knowledge may
have contributed to students’ increased acceptance of evolution for at least some students despite the lack of a statistically significant main effect of the intervention.

**Understanding of evolution.** Unlike the MATE, the designers of the CINS did not create categories that reflected low, moderate, and high understanding of natural selection and evolution. The mean CINS scores for the intervention class were low both before (9.12) and after (11.12) the evolution unit hovering around 50% of understanding. The relatively low understanding scores after the evolution unit may be attributed to the fact that the CINS is a much longer instrument than the MATE. It contains the same number of questions, but instead of statements followed by a Likert scale, as found in the MATE, the CINS contains paragraphs about organisms such as cave salamanders followed by conceptually-based questions. Much more reading is involved, and survey fatigue may occur. However, target students’ definitions of evolution after the unit demonstrated that four of the six students still defined evolution incorrectly. Examining their definitions leads to the conclusion that teleological thinking patterns were still very strong. This conclusion is not surprising considering previous research (Kelemen, 2012; Kelemen & Rosset, 2009).

**Summary of Qualitative Findings**

The qualitative data found in the pre- and post-unit interviews and other qualitative data sources led to several conclusions. First, while not all students need help crossing cultural borders between the science classroom culture and their at-home cultures, no one complained about an instructor acting as a facilitator for those who did need assistance crossing borders. Second, the research exposed previously unidentified factors that influenced students’ worldviews about science and religion (such as popular culture figures) and obstacles that impeded their acceptance of evolution (such as The Road to Homo Sapiens
illustration). Third, students look to authority for evidence that supports their worldview and can see this authority as infallible and on a different level from themselves. Fourth, some previous research identified negativity on the part of religious students asked to learn about evolution, and this research expanded upon this topic by showing that even students who accept evolution feel negatively about discussing the topic and/or show empathetic understanding for religious students who feel negative emotions when evolution is discussed in the science classroom. Finally, borderless students exist, who do not fall into Aikenhead’s previously identified cultural border crossing categories because there is no border for them to cross between home and the science classroom. The category of borderless students is necessarily broad because it must include students like Patterson and Neko who do not hold any religious beliefs about the diversity of life on Earth and students like Brandi who grew up with any sort of conflict between religious and scientific worldviews about evolution already resolved.

**Implications for Future Research**

Previous research discusses the role of instructors in students’ understanding and acceptance of evolution. Results from this research suggest that more research should be undertaken to examine how others influence students’ thinking about evolution. Evolution-related social media posts shared by friends and family contain thoughts and opinions on evolution made by politicians like Ben Carson (current Secretary of Housing and Urban Development) and Bobby Jindal (former governor of Louisiana). Target students in this research mentioned others such as Mayim Bialik, Tim Allen, Bill Nye, and Ken Ham when talking about evolution. Research on how media figures like these influence students’ understanding and acceptance of evolution would add important contributions to science
education research. Research has examined how social media discussions affect opinions and attitudes about climate change as a valid scientific issue. For instance, a social network analysis indicated that partisan negative beliefs are widespread on social media and that most social media users only interact with others who are like-minded in their beliefs about climate change (Williams, McMurray, Kurz, & Lambert, 2015). While traditional sources of media such as encyclopedias, schools, and mainstream newspapers and magazines were formerly the single source of information for the general public, new social media sources can now provide everyone with unlimited information (Porten-Chee & Eilders, 2015), and while this has been studied related to climate change, it should be studied in relation to evolution as well.

One recent study describes social media posts about evolution made by Miley Cyrus, Kirk Cameron, Chuck Norris, and Justin Bieber (Arnocky, Bozek, Dufort, Rybka, & Hebert, 2018). Their research with university students showed that an opinion regarding evolution offered by a male celebrity affected students’ evolution acceptance. In addition, the male celebrity’s post was more effective at influencing students’ opinions about evolution than evidence presented by a male expert (Arnocky et al., 2018). More research of this nature could be undertaken to examine what role celebrity opinions play in students’ understanding and acceptance of evolution in the hyper-connected 21st century.

Future research should also examine whether The Road to Homo Sapiens serves as an obstacle for people with a religious worldview to accept evolution in other areas of the US and world. This research implies that this illustration acted as a barrier to acceptance of evolution for several of my religious target students. In addition, many students in the intervention class reacted animatedly when Mr. Gloucester announced that The Road to
Homo Sapiens was not a scientifically valid graphic, so this illustration should be researched as a source/cause of a common alternative conception about hominid evolution. It would be valuable to research this issue as related to both students and the general public.

Finally, while not related to these research questions, this dissertation research indicates that future research is needed on several other topics related to evolution. First, target students continued to use teleological wording in their post-unit definition of evolution after the evolution unit. More research on how an intervention affects teleological thinking and the effects of thinking teleologically could help shed light on teleological obstacles to learning about evolution. Most previous research opines that thinking teleologically is negative, but is this only an opinion? Zohar and Ginossar (1998) explained that teleological thinking is useful in biology, because not all natural processes can be “reduced to physical-chemical mechanisms” (p. 683). In addition, a study found that teleological explanations can be useful when used regarding important concepts in chemistry (Talanquer, 2007). However, other research has shown that teleological thinking leads to improved understanding about natural selection as the mechanism for evolution (Stover & Mabry, 2007). Further research could help determine whether teleological thinking is detrimental to student learning about evolution.

Finally, George remarked that it was easy for him to envision others struggling to cross cultural borders because he knew lots of people with different beliefs. Perhaps the degree of heterogeneity in class makeup contributes to the effect of a cultural border crossing intervention. A multi-school study that compares the results of cultural border crossing interventions between schools with heterogenous students (as related to worldview) and homogenous students could provide data in response to that hypothesis. Previous research
has been done on anti-evolution Christian students’ navigation of the tension often surrounding evolution (Winslow et al., 2011) and further research comparing students at religious and non-denominational universities would be helpful as well.

**Implications for Practice**

One simple pedagogical change that could provide a large return on investment would be direct instruction regarding The Road to Homo Sapiens illustration. Since several target students wondered aloud why no one had ever explained that the illustration should not be regarded as a scientific diagram, explaining this in all biology classrooms seems necessary. Classrooms may already discuss common alternate conceptions about evolution and focusing on The Road to Homo Sapiens as an obstacle to belief and understanding is simple, yet imperative, based on the results from this dissertation research. In addition, adding a specific discussion of teleological thinking related to evolution would be relatively easy to implement.

A larger pedagogical change would be for science educators to implement the cultural border crossing intervention, which is a pedagogical strategy that is inclusive for students with various worldviews (Barnes & Brownell, 2018). Before the intervention, Mr. Gloucester’s direct instruction focused on biological concepts related to evolution and natural selection. Mr. Gloucester reviewed the science education literature on cultural border crossing and collateral learning and used a researcher-designed intervention to successfully change his pedagogical strategies for the intervention class. He used a script in class to ensure he covered all the points in each day’s mini-lesson. Professional development for high school and university science educators could enable them to use a version of this cultural border crossing intervention modified as needed for their classrooms. Previous
research indicates that using cultural border crossing as a model has been successful in a high school biology classroom (Borgerding, 2017).

Limitations

One potential limitation in this study is the number of cases. The most heterogenous group of students possible was compiled by selecting interview participants based on their pre-unit MATE scores, but this method does not guarantee heterogeneity of worldview. Choosing students with high, medium, and low MATE scores also allowed for sampling of typical cases, a strategy useful for field testing the new intervention (Gall et al., 2003) but may not have led to choosing students who had extensive thoughts about collateral learning and cultural border crossing.

In addition, many students did not complete the BIO 110 class. In the control class, 17% of the students dropped the class between the pre-unit instruments and the post-unit instruments. In the intervention class, 11% of students dropped the class between the pre-unit and post-unit administrations of the instruments. In addition, between five and eight students dropped each class before the evolution unit began. In the intervention class, four students did not return signed consent forms. If all students in both sections had returned signed consent forms and completed the entire class, the sample size would have been greater.

Another limitation could be related to the dosage size. Since Mr. Gloucester’s cultural border crossing intervention comprising 40% of class time included partner activities that were not part of his typical pedagogy, results may have also been related to the insertion of new class activities. In addition, any concept-based lecturing that was lost due to the
cultural border crossing dosage may have affected students’ understanding of evolution and natural selection.

Qualitative data is often not easily generalizable (Gall et al., 2003). However, limited generalizations can be drawn related to students whose worldviews affect their understanding and acceptance of evolution. The intention of this research was not to uncover universally generalizable findings as that is not the nature of qualitative research. Instead, the findings might be applicable in similar educational contexts.

**Future Research Plans**

Further research on the topic of cultural border crossing and collateral learning as related to evolution teaching and learning is planned. Current research on the second CBC iteration that includes teleological thinking will inform whether direct instruction about teleological thinking and the inaccuracy of The Road to Homo Sapiens illustration as a scientific explanation for modern humans affect students’ understanding and acceptance of evolution.

**Summary**

In this chapter, summaries and highlights of the results were provided. This study sought to understand how a pedagogical intervention might affect students’ understanding, acceptance, and reactions to learning about evolution, especially if it conflicted with a student’s current worldview. Data that shows the cultural border crossing intervention did not have a statistically significant main effect but led to positive affective reactions to evolution were presented. Additionally, while assistance with cultural border crossing may not be necessary for all students in a biology class, this research suggests that all students can understand why it might be useful for others. Importantly, none of the target students
complained about the intervention, even if it was not personally helpful because they were successful border crossers or borderless students.

Our current political environment in the United States has influential anti-science leaders at the helm of various federal, state, and local governmental or public organizations. States and school boards continue to argue about whether Creationism or Intelligent Design should be included in the science classroom. It is imperative that educators know how to best reach all their students to advocate for understanding and acceptance of evolution. As many issues such as vaccines and extinction affect everyone, providing methods for everyone to understand evolution and its mechanisms could not come at a more opportune time. Asking students to discard religious or other cultural worldviews has not worked in the past, so we should instead learn more about students’ culture and worldviews and how these factors affect their understanding and acceptance of evolution. Valuing everyone’s beliefs and various sources of knowledge through acknowledging and emphasizing cultural borders and collateral learning will lead to a deeper understanding of critical biological concepts.
REFERENCES


APPENDICES
Appendix A

Conceptual Inventory of Natural Selection

D.L. Anderson and K.M. Fisher

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 finch that migrated to the islands one to five million years ago (Lack, 1940). Recent DNA analyses support the conclusion that all of the Galapagos finches evolved from the warbler finch (Grant, Grant & Petren, 2001; Petren, Grant & Grant, 1999). Different species live on different islands. For example, the medium ground finch and the cactus finch live on one island. The large cactus finch occupies another island. One of the major changes in the finches is in their beak sizes and shapes, as shown in this figure.

Choose the one answer that best reflects how an evolutionary biologist would answer.

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 stable.
   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 scarce, 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.
   c. When food and water are scarce, 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 relatively stable, with some fluctuations.
   c. the population dramatically increases and decreases each year.
   d. the population will decrease steadily.
Appendix B

MATE Questionnaire

Professor’s Name: ____________________ Secret Number: _____

Measure of Acceptance of the Theory of Evolution

For each statement, please write the letter that indicates your agreement or disagreement using the following scale:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly agree</td>
<td>Agree</td>
<td>Undecided</td>
<td>Disagree</td>
<td>Strongly disagree</td>
</tr>
</tbody>
</table>

1. _____ Organisms existing today are the result of evolutionary processes that have occurred over millions of years.
2. _____ The theory of evolution is incapable of being scientifically tested.
3. _____ Modern humans are the product of evolutionary processes which have occurred over millions of years.
4. _____ The theory of evolution is based on speculation and not valid scientific observation and testing.
5. _____ Most scientists accept evolutionary theory to be a scientifically valid theory.
6. _____ The available data are ambiguous as to whether evolution actually occurs.
7. _____ The age of the earth is less than 20,000 years.
8. _____ There is a significant body of data which supports evolutionary theory.
9. _____ Organisms exist today in essentially the same form they always have.
10. _____ Evolution is not a scientifically valid theory.
11. _____ The age of the earth is at least 4 billion years.
12. _____ Current evolutionary theory is the result of sound scientific research and methodology.
Scale Reminder:

<table>
<thead>
<tr>
<th></th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Undecided</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.</td>
<td>Evolutionary theory generates testable predications with respect to the characteristics of life.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>The theory of evolution cannot be correct since it disagrees with the Biblical account of creation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Humans exist today in essentially the same form in which they always have.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.</td>
<td>Evolutionary theory is supported by factual, historical, and laboratory data.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Much of the scientific community doubts if evolution occurs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18.</td>
<td>The theory of evolution brings meaning to the diverse characteristics and behaviors observed in living forms.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19.</td>
<td>With few exceptions, organisms on earth came into existence at about the same time.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20.</td>
<td>Evolution is a scientifically valid theory.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Appendix C

Interview Protocol for Undergraduate Biology Students & Evolution Research

Pre-Evolution Unit Interview

1. Tell me about your experience at Wake Tech so far and what you are studying and what your goals are.

2. Tell me about why you chose to take BIO 110.


4. In Costa Rica, there are many species of frogs, including poison dart frogs and leaf frogs. How did these species of frogs arise?

5. Darwin found that finches in the Galapagos Islands had different types of beaks that allowed them to specialize in various types of food. How did this happen?

6. How do you view the relationship between religious and scientific explanations for how the Earth came to have such diversity in living things? Possible follow up if they say they see conflict between religion and science: What things do science explain? What things do religion explain? Another possible follow up if they see that both science and religion can be useful: Is it possible, beneficial, or desirable to be able to hold two different sets of explanations for the same phenomenon at the same time?

7. What were some of the interesting things you learned in middle or high school Biology/Life Science classes?

8. Do you have any memories of learning about evolution in school or outside of school?

9. What do you know about evolution?
10. What questions do you have about evolution?

Post-evolution Unit Interview

1. How did Mr. Gloucester begin the unit on evolution?

2. I’m going to ask you to compare and contrast what you learned about evolution in BIO 110 to what you have previously learned at school, home, church, etc.

2a. How do they align?

2b. How do they conflict or differ?

3. How do you feel when evolution is discussed in class?

4. Have you applied what you’ve learned about evolution to your life?

5. What has changed, if anything, in your thinking about evolution? Ask questions about frogs and finches from above again.

6. How can you relate evolution to nature and/or your own life?

7. Would you take another class that focuses on evolution? Why or why not? What questions do you still have about evolution?

8. [If any conflict was raised previously between scientific and home/church views]: do you think scientific views of evolution and your [home/church] views are in direct conflict? Or do you think they address different issues/questions?

9. How do YOU think BIO 110 could be taught so that people with pre-existing views of how life on Earth changes over time experience less conflict with scientific views of evolution?
Appendix D

Lesson Plans for BIO 110 Intervention

Day One: Who do you ask?

Why is this important? We use different sources of information when answering questions. Jegede says that collateral learners can use more than one source of knowledge while studying science. For example, parallel collateral learners might use two different sources of knowledge in two different places. They might answer questions about the beginning of the universe using a scientific source of knowledge while in Biology class, and a religious source of knowledge while in church. My theoretical framework says that students should be able to use multiple sources of knowledge to answer questions about the world, not only one. We should be encouraging students to leverage different sources of knowledge, rather than talking them into believing in only one (science).

Say: Some scientific issues are discussed often in places other than science labs and conferences. One of these issues is evolution. You might hear the word “evolution” at school, at a place of worship, or in a doctor’s office. If you have questions about evolution, who do you ask? In this activity, we’ll talk about different sources of knowledge and what questions they answer. For example, if you wanted to know how many planets there are outside of our solar system, who would you ask? (Possible answers: a scientist, the internet, an astronomer). What kind of source of knowledge is that? (scientific). If you wanted to know what the meaning of life is, who would you ask? (a philosopher, a religious expert, a friend). What source of knowledge is that? (philosophy, religion).

Think about the different sources of knowledge that you draw from in your own life. I’m going to give you a set of cards. I want you and your table partner to group these cards based on the sources of knowledge you would use to answer each one. You can create as many or as few categories as you’d like.

**We need to group the non-consenters together.**

During the activity: Walk around and ask questions as needed to facilitate the activity. Make sure students have their groups labelled, like “can be answered with science” or “can be answered with religion”. **Katie needs to take pictures**

After students finish: Ask pairs if they would like to share. Compare and contrast between groups. Ask follow-up questions as applicable, such as, “Are some questions answered by more than one category?” (We hope they answer yes.) “What evidence do different sources of knowledge depend on to answer questions?” (They may say that religion depends on faith and science depends on evidence from experiments.) End by asking “Can an astrophysicist who believes the Big Bang provides the best evidence for
the creation of our universe also believe that a god of some sort created the universe?”
(There will probably be a variety of answers. Some students may think that scientists
can’t be religious, whereas others may think that scientists can believe in evolution
guided by a god.)
Questions: What happens to us after we die? How do we know what is right and what is
wrong? What is a cell made of? Should people be allowed to own assault weapons for
personal use? Why should we recycle? When did humans appear on Earth? How did the
Grand Canyon form? Is an animal’s life more or less important than a human’s life? How
are babies created? Do oil refineries cause pollution? What relationship, if any, is there
between great apes like gorillas and humans? How did there come to be so many types of
life forms on Earth?
Background information:
Scientism: the methods of science alone are sufficient for discovering everything there is to
know about the universe
Deism: God created all things and set the universe in motion, but no longer actively directs
natural phenomena
Theism: God actively intervenes in the world
Collateral learning: when students make use of multiple competing sources of knowledge
• Parallel—students can only use one compartmentalized source at a time
• Secured—conflict between sources of knowledge is resolved and there is
  interplay between sources
• Dependent—students retain and modify their original source of knowledge
  when confronted with new, conflicting information
• Simultaneous—coincidentally, students make a connection between one
  source of knowledge when learning from another source of knowledge (ex.
  Understanding photosynthesis when the water they are cooking greens in at
  home turns green)

Day Two: Creation Stories – Culture

Why is this important? Students may think the creation story they are familiar with (quite
likely the Garden of Eden story) is the only one. This activity is designed to have students
use other cultures’ perspectives to think about how humans came to live on Earth. The
evolution of humans is often a part of evolution that students grapple with. This lesson will
help them examine their beliefs on human evolution and what source(s) of knowledge they
use when thinking about human evolution. **Remember, we will use the term creation
story, not the term myth.**
Say: In the last class, we talked about sources of knowledge. One source of knowledge
is culture. Culture is the attitudes, customs, and beliefs of a certain group of people at a
particular place and time. Many people believe they can learn about the creation of
humans through the creation story of their culture. Here is one example. (Show slide
of the Haida sculpture and tell the story of Raven and the first people https://www.eldrbarry.net/rabb/rvn/first.htm).

After the great flood had at long last receded, Raven had gorged himself on the delicacies left by the receding water, so for once, perhaps the first time in his life, he wasn't hungry. but his other appetites, his curiosity and the unquenchable itch to meddle and provoke things, to play tricks on the world and its creatures, these remained unsatisfied.

Raven gazed up and down the beach. It was pretty, but lifeless. There was no one about to upset, or play tricks upon. Raven sighed. He crossed his wings behind him and strutted up and down the sand, his shiny head cocked, his sharp eyes and ears alert for any unusual sight or sound. The mountains and sea, the sky now ablaze with the sun by day and the moon and stars he had placed there, it was all pretty, but lifeless. Finally Raven cried out to the empty sky with a loud exasperated cry.

And before the echoes of his cry faded from the shore, he heard a muffled squeak. He looked up and down the beach for its source and saw nothing. He strutted back and forth, once, twice, three times and still saw nothing. Then he spied a flash of white in the sand.

There, half buried in the sand was a giant clamshell. As his shadow fell upon it, he heard another muffled squeak. Peering down into the opening between the halves of the shell, he saw it was full of tiny creatures, cowering in fear at his shadow.

Raven was delighted. Here was a break in the monotony of the day. But how was he to get the creatures to come out of their shell and play with him? Nothing would happen as long as they stayed inside the giant clamshell.

They were not going to come out as long as they were so afraid of him. So Raven leaned over his head, close to the shell, and with all the cunning and skill of that smooth trickster's tongue, that had so often gotten him in and out of so many misadventures during his troubled and troublesome existence, he coaxed and cajoled and coerced the little creatures to come out and play in his wonderful shiny new world.

As you know the Raven has two voices, one harsh and strident, and the other which he used now, a seductive, bell-like croon which seems to come
from the depth of the sea, or out of the cave where winds are born. It is an irresistible sound, one of the loveliest in the world.

It wasn't long before first one and then another of the little shell-dwellers emerged from the shell. Some scurried back when they saw the Raven, but eventually curiosity overcame their caution and all of them had crept or scrambled out.

Very strange creatures they were: two legged like Raven, but otherwise very different. They had no feathers. Nor fur. They had no great beak. Their skin was pale, and they were naked except for the dark hair upon round, flat-featured heads. Instead of strong wings like raven, they had thin stick-like arms that waved and fluttered constantly. They were the first humans.

Now, you will form groups of three and find a creation story of a culture or religion to share with the class using web resources. Be prepared to share a short version of the story with the class.

**We need to group the non-consenters together.**

During the activity: Walk around and ask questions as needed to facilitate.

After students finish: Ask several groups to share their creation stories. Ask the class follow-up questions as applicable, such as, “What did these stories have in common?”, “How did they differ?”, “How were these stories shared?”, “What evidence supports these stories?”. Make sure to ask “Can a Haida believe their creation myth AND a scientific account of how humans came about? Or do they need to give up their religious or cultural beliefs to accept scientific evidence as valid?” (Again, we are hoping that they will agree that people can hold collateral knowledge, either as parallel, dependent, or collateral knowledge, a la Jegede.)

Day Three: Religious Doctrines

Why is this important? Students often believe that their religious doctrine dictates whether they can believe in evolution. However, this is often not the case. We are giving student groups a random religion so that they will not feel any discomfort regarding speaking about their own religion.

Say: In the last class, we talked about culture as a source of knowledge and learned about various creation stories. Religion is an important part of many cultures. Today, we are going to look at religious doctrine (a set of beliefs) to see how different religions consider evolution. We will be looking at how one source of evidence (religion) considers another source of evidence (science). Here’s one example from kabbalah.org: “You can learn about evolutionary processes in our world through books that were written by scientists, physicists, biologists and others. But how the evolution of the soul is performed is what we really need to understand.”
Ask: What does this say about considering various sources of knowledge? Would someone who follows the Kabbalah be able to believe in both science and evolution. (Yes, according to the religious doctrine.)

Say: Now, I will give you the name of a religion, and you’ll work in groups to look up their doctrine on evolution. You can use the internet and try to make sure you are using a reliable source. If you are uncomfortable with the religion you are given, please let me know. When you’re finished, fill in what you found on the chart on the board.

**It doesn’t matter how we break them into groups because we are actually not taking any data from today’s activity.** We need 11 groups.

<table>
<thead>
<tr>
<th>Religions: Catholic, Islam, Mormon, Southern Baptist, Methodist, Pentacostal Holiness, Buddhist, Hindu, Presbyterian, Judaism, Episcopal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Answers (from Pew Research Center (2017) website):</strong></td>
</tr>
<tr>
<td>Buddhism—most Buddhists have no problem reconciling evolution with their religious beliefs, as it aligns nicely with the Buddhist belief that life is impermanent</td>
</tr>
<tr>
<td>Catholicism—believe that science is the best explanation for the development of life, BUT it is directed by God, and our souls are created by God</td>
</tr>
<tr>
<td>LDS—no official position on evolution, but natural selection is a question for science</td>
</tr>
<tr>
<td>Episcopal—God can create using any manner (including evolution), and have publicly rejected Creationism and Intelligent Design</td>
</tr>
<tr>
<td>Hinduism—no official belief, but many Hindus do not find evolution incompatible with their religious beliefs</td>
</tr>
<tr>
<td>Islam—the Koran teaches that Allah created humans in today’s form. Conservative Muslims generally believe in a literal interpretation of the Koran, while more liberal Muslims think that humans were created by God but might have evolved through natural selection</td>
</tr>
<tr>
<td>Judaism—believes that humans were created by God, but don’t find a conflict between their faith and evolutionary theory</td>
</tr>
<tr>
<td>Southern Baptists—reject evolution and believe in the science of Creation Science</td>
</tr>
<tr>
<td>Methodists—2008 passed a resolution saying evolution is not in conflict with their faith, and many of the scientific references in the Bible should be taken as metaphorical</td>
</tr>
<tr>
<td>Pentacostal Holiness—no agreement, but fall into one of three categories 1) Young Earth Creationists, 2) Old Earth Creationists, 3) Theistic Evolutionists</td>
</tr>
</tbody>
</table>
When they finish:

Discuss similarities and differences of religious doctrines on evolution. Make sure to point out the evolution (and specifically theistic evolution) is almost always compatible with religious beliefs. Ask students what surprised them. (Hopefully like me, a lot of students were surprised that so few religions actively disavow evolution.) Ask students if they think religious leaders can also believe in evolution. Tell students if they'd like to learn more about religious leaders who support evolution, they can Google and read about the Clergy Letters Project. The website address is http://www.theclergyletterproject.org/

Day Four: Why can’t we just skip evolution?

Why is this important? Even though we’ve shown the students that most religions are not opposed to evolution as a mechanism that causes humans and other life to change over time, some students will still believe that evolution is not an important part of biology. Students with conflicts should feel that they are in a safe environment, as we have discussed collateral learning, and how more than one source of knowledge can be used to answer questions about evolution. Since you will have discussed evolution related content by now, it’s time to focus them on the science behind evolution.

Say: Take a look at our question for today. Many students have asked this question in high school and college biology classes over the years. What do you think are some of the typical objections to teaching evolution? (Some possible answers include the Earth is younger than what scientists say, there are missing links, it’s just a theory, scientists made up some of the fossils they used as evidence [i.e. the Piltdown Man], we can’t see evolution happening).

You brought in your homework for today, which was to complete the school board scenario. Would anyone like to share what they wrote? Ask: What does science need to provide in order for people to accept it as truth? (evidence) Is scientific evidence based on the results of one experiment? (Rarely; scientists do thousands of experiments in order to create a theory like gravity, evolution, or the germ theory.) Why do we need to teach evolution? (it is a foundational concept in biology).

Say: What is the evidence for evolution? (insert all the evidence you talk about) Today’s lecture is going to cover those pieces of evidence.
Appendix E

Evolution Autobiography Assignment

Write a one- to two-paged autobiography about your experience regarding evolution. You will be graded on completeness, organization, and clarity, but not on accuracy. Keep the following questions in mind as you write:

● When did you first hear of evolution?

● What sources did you learn about evolution from? Did they give you different information?

● When were you first taught about evolution in a classroom?

● How did you feel when you first learned about it? Did it make you feel anxious?

● What viewpoints do your friends/family hold about evolution?

● Did the theory of evolution conflict with your personal beliefs when you learned about it?

● Do you view evolution differently now than when you first learned about it?

● If you had to give someone a short definition of evolution, what would it be?

[based on Martin-Hansen (2008)]
Appendix F

Epistemological Questions

Create categories that show which sources of knowledge can answer the following questions and place each card in the correct category(ies).

<table>
<thead>
<tr>
<th>What happens to us after we die?</th>
<th>When did humans appear on Earth?</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do we know what is right and what is wrong?</td>
<td>How did the Grand Canyon form?</td>
</tr>
<tr>
<td>What is a cell made of?</td>
<td>Is an animal’s life more or less important than a human’s life?</td>
</tr>
<tr>
<td>Should people be allowed to own assault weapons for personal use?</td>
<td>How are babies created?</td>
</tr>
<tr>
<td>Why should we recycle?</td>
<td>Do oil refineries cause pollution?</td>
</tr>
<tr>
<td>Do humans and chimps share DNA?</td>
<td>What makes a good parent?</td>
</tr>
<tr>
<td>How old is the Earth?</td>
<td>Do aliens exist?</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>What does your liver do?</td>
<td>How was the world created?</td>
</tr>
<tr>
<td>Should I use my turn signals?</td>
<td>Is there ever a good reason to murder someone?</td>
</tr>
<tr>
<td>What’s the spiciest type of pepper?</td>
<td>Which color paint is best for a kitchen?</td>
</tr>
</tbody>
</table>
Appendix G

Field Notes Sample

Notes from 3/21--Day Two:
Students researched creation stories and shared them. First two were Hindu but were
different stories. Students were very engaged. Some groups disagreed about which stories
they wanted to share. Mr. G pointed out that both stories were subdividing something. Amy
shared the Egyptian one. The first lifeform came from the sun. In the Hindu one, the first
humans and all the stuff came from ghee.
Mr. G. asked how they get shared. Carrie and Elyse said orally until writing came. Another
student shared the story of the rainbow serpent which came up through the ground in
Australia. Student in the back said—that’s crazy!
Elyse said a lot of stories had water. Mr. G mentioned that there were a lot of flood stories.
Carrie agreed. Neko said it’s probably because most of the groups lived near water. Mr. G.
asks if there’s evidence that these stories actually occurred. Elyse says—no, unless you can
find god and ask them. One student related to the game telephone—most of the stories might
be totally different than the way they were originally told. Mr. G. says most stories seemed
to start by trying to explain light and dark. Several students nodded their heads.
Mr. G. asks whether people like the Haida could use their creation story as a cultural
explanation for the diversity of life on Earth while also believing in evolution. Elyse says yes. Amy says-- it depends on which part—not if you believe in the Raven story and the idea
that we came from apes. Elyse says-- isn’t there a story about how we evolved from the
water?
Now switched to lecture.
Returned to biological species concept. Talked about limitations. Can’t use it on asexually
reproducing organisms or extinct species.
We’re not going to do this history of Darwin like we did with Mendel. We’re just going to
talk about his ideas. Scientists were aware that things were changing in the 1850s, and there
were a lot of animal breeders at the time and that there was variation. No one had a good
explanation for how things changed over time. They were using the word transmutation at
the time rather than evolution. Darwin came up with the mechanism of natural selection.

Writes the 4 mechanisms that lead to evolution on the board: natural selection
(Darwin’s contribution), mutation, genetic drift, gene flow (migration)
Appendix H

School Board Scenario

Name - _____________________________________ #-- _______________________

Science in the Public Schools – School Board Scenario
(used with permission from Bloom, M.A, & Binns, I.C.)

Scenario:
You have been elected to your local school board. There is currently a motion to alter the science curriculum in the local junior high and high schools regarding their presentation of evolution. Currently, Darwinian evolution is the only explanation provided for the diversity of life on Earth. A growing population of concerned parents are advocating for introducing Intelligent Design and/or Creationism into the unit on Darwinian evolution. A brief description of Darwinian evolution, Creationism, and Intelligent Design are provided on the back of this page. Your opinion on this matter should be based upon your understanding of what is or is not scientific, so begin by defining the word, “Science”. Then, read the description of each position and, based upon your understanding of science, answer the following questions on the answer form provided. Be sure to justify your position.

What is Science?

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**Darwinian Evolution:** Darwinian evolution explains the diversity of life on Earth as having evolved from a common ancestor. According to evolutionary theory, life evolved from non-living matter approximately 3.8 Billion years ago in the form of bacteria and that through genetic drift, natural selection, and speciation, millions of distinct species have evolved and gone extinct over the subsequent billions of years. Evolutionary theory claims that humans evolved approximately 200,000 years ago (about 65 million years after the dinosaurs went extinct).

**Creationism:** Generally speaking, Young Earth Creationists (YECs) believe Earth to be between 6,000 and 10,000 years old and base this judgment on Biblical genealogies that trace the birth of Jesus back to Adam. Creationists hold fast to literal interpretations of Genesis account (as found in the first book of the Christian Bible) of the world being formed in just 6 days and they date the Earth using this interpretation. YEC’s generally reject modern-day physics and chemistry derived radioisotope dating methods, geo-physical explanations of geological formations, as well as plate tectonics. They attribute such structures as the Grand Canyon and geological strata to Biblical events such as the Genesis flood and a vast water vapor canopy that existed prior to the flood. Further, they reject evolutionary theory and believe that plants and animals found today were created in their current form and that extinct species (e.g. dinosaurs) lived contemporaneously with mankind.

**Intelligent Design:** Intelligent Design (ID) is a recently developed idea, which is being promoted as a viable alternative to a pure creationist or evolutionist position. ID developed from William Paley’s *Natural Theology* (1802), which put forth the now-famous watchmaker argument, which claims that when one observes the complexity of a watch, one knows, inherently that an Intelligent Designer was responsible for its creation. ID advocates argue that structures and systems such as the flagellum and the proteins involved in blood clotting are too complex to have evolved and claim that with the removal of any component of them, they would cease to function. Because of the extreme unlikelihood that they could have evolved, they maintain that one must attribute their existence to a supernatural creator.

*Creationism – How will you vote?*
1. Would you vote to allow Creationism to be added to the science curriculum? Why or why not?
Intelligent Design – How will you vote?

2. Would you vote to allow Intelligent Design (ID) to be added to the science curriculum? Why or why not?

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## Appendix I

### Codebook

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<thead>
<tr>
<th>Code</th>
<th>Definition</th>
<th>Example</th>
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<tbody>
<tr>
<td>culture (C)</td>
<td>&quot;norms, values, beliefs, expectations, and conventional actions&quot; of a group (Phelan 2015, p. 228)</td>
<td>We watch a lot of videos about animals in my family. (specifically home culture)</td>
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<tr>
<td>microculture (MC)</td>
<td>&quot;within every culture there are subgroups or social communities that more or less share unique combinations of norms, values, beliefs, expectations, and conventional actions&quot;</td>
<td>At Environmental Club meetings, we talk about how climate change might affect evolution.</td>
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<td>cultural border crossing (CBC)</td>
<td>&quot;the transition from a student's life-world into a science classroom is a cross-cultural experience for most students&quot; (A&amp;J, p. 271)</td>
<td>What we learn in science class is so different from what I learn about at home.</td>
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<td>successful cbc (SCBC)</td>
<td>&quot;We do not recognize that a cultural border potentially exists between the two microcultures&quot; (A&amp;J, p.272)</td>
<td>It never occurred to me that some people's beliefs might contradict evolution.</td>
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<tr>
<td>managed cbc (MCBC)</td>
<td>&quot;when we feel a degree of discomfort with another microculture we might be unwilling to engage in risk-taking social behavior&quot;</td>
<td>I don't raise my hand in science class because I'm not sure I believe in all of it.</td>
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<td>hazardous cbc (HCBC)</td>
<td>&quot;when our self-esteem is in jeopardy, we tend to react in various ways to protect our egos&quot;</td>
<td>I don't talk in groups because my classmates will think I'm stupid for not believing in evolution.</td>
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<td>impossible cbc (ICBC)</td>
<td>&quot;if psychological pain is involved, avoidance is our natural response&quot;</td>
<td>I skipped bio in HS all the time because it was too confusing to think the words of Genesis might not be true.</td>
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<td>collateral learning (CL)</td>
<td>&quot;constructing scientific concepts side by side and with minimal interference and interaction with their indigenous concepts related to the same physical event&quot; (A&amp;J, p.276)</td>
<td>At school, we talk about hominids, but at home we talk about Adam and Eve.</td>
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<tr>
<td>parallel collateral learning (PCL)</td>
<td>&quot;the conflicting schemata do not interact at all, the compartmentalizing technique&quot; (A&amp;J, p.278)</td>
<td>At school, we talk about hominids, but at home we talk about Adam and Eve.</td>
</tr>
<tr>
<td>secured collateral learning (SCL)</td>
<td>&quot;conflicting schemata consciously interact and the conflict is resolved in some manner&quot; (A&amp;J, p.278)</td>
<td>Science and religion are both helpful because they explain things.</td>
</tr>
<tr>
<td>dependent collateral learning (DCL)</td>
<td>&quot;a schema from one worldview or domain of knowledge challenges another schema from a different worldview, to an extent that permits the student to modify an existing schema without radically restructuring the existing worldview, students are not usually conscious of the conflicting domains&quot; (A&amp;J, p. 278)</td>
<td>I think probably God is in charge of how things evolve.</td>
</tr>
<tr>
<td>concept</td>
<td>description</td>
<td>example</td>
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<td>-------------------------------</td>
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<tr>
<td>simultaneous collateral learning (SCL)</td>
<td>&quot;a unique situation in which learning a concept in one culture can facilitate the learning of a similar concept in another culture. It does not happen often and is usually a coincidence&quot; (A&amp;J, p.280).</td>
<td>We learned about how mutations can be beneficial, harmful, or neutral and that day I went home and watched my blind cat sniff out a mouse before our other cat. It made me realize her mutation was beneficial.</td>
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<td>teleology (Tel)</td>
<td>the idea that natural processes are guided by a purpose or goal</td>
<td>They evolved so everyone could survive.</td>
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<tr>
<td>general misconception (Mis)</td>
<td>general lack of understanding about how evolution works</td>
<td>When people started interacting, they changed.</td>
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<tr>
<td>Anthropomorphism (Ant)</td>
<td>attributing human emotions to non-humans</td>
<td>The frog was sad because it had to die.</td>
</tr>
<tr>
<td>Sources of knowledge (SOK)</td>
<td>discussing a source of knowledge</td>
<td>My family and I had discussions about it.</td>
</tr>
<tr>
<td>Personal characteristics (PC)</td>
<td>reflecting on one's own personality</td>
<td>I was the type to ask a lot of questions.</td>
</tr>
<tr>
<td>Persisting questions (PQ)</td>
<td>a question a student does not understand related to evolution</td>
<td>I still don't understand why there are still apes.</td>
</tr>
<tr>
<td>Evidence (E)</td>
<td>what is needed to know/believe in something</td>
<td>I don't think you can decide if you don't know anything about it.</td>
</tr>
<tr>
<td>Emotions (Emo)</td>
<td>how a student feels about learning</td>
<td>I was really nervous to take science.</td>
</tr>
<tr>
<td>Accurate evolution knowledge (AEK)</td>
<td>anything accurate about the theory of evolution believed by the student</td>
<td>I know that traits are passed on from parents to offspring.</td>
</tr>
<tr>
<td>Theistic evolution (TE)</td>
<td>the idea that God started evolution and then let it happen</td>
<td>Like he would just start this and see what happens.</td>
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<tr>
<td>Nature of Science (NOS)</td>
<td>students talk about the tentative nature of science or something of the sort</td>
<td>Science explains observable, natural phenomena.</td>
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