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STUDENT ACQUISITION OF BIOLOGICAL EVOLUTION-RELATED MISCONCEPTIONS: THE ROLE OF PUBLIC HIGH SCHOOL INTRODUCTORY BIOLOGY TEACHERS

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A DISSERTATION APPROVED FOR THE
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PROLOGUE

This dissertation is prepared in a journal-ready format. The first part of the dissertation consists of three journal articles which have been prepared for submission to refereed journals. Manuscript I, *A Regional Study of the Prevalence of Biological Evolution-related Misconceptions Held by Introductory Biology Teachers,* is prepared for the journal *Evolution: Education and Outreach.* Manuscript II, *A Study Identifying Biological Evolution-related Misconceptions Held by Prebiology Students,* is also prepared for the journal *Evolution: Education and Outreach.* Manuscript III, *Teachers Teaching Misconceptions: A Study of Factors Contributing to High School Biology Students' Acquisition of Biological Evolution-related Misconceptions,* is prepared for the *Journal of Research in Science Teaching*.

DISSERTATION ABSTRACT

In order to eliminate student misconceptions concerning biological evolution, it is important to identify their sources. The purposes of this study were to: (a) identify biological evolution-related misconceptions held by Oklahoma public high school Biology I teachers; (b) identify biological evolution-related misconceptions held by Oklahoma public high school students prior to and following instruction in Biology I course curriculum; and (c) identify which, if any, biological evolution-related misconceptions held by Oklahoma public high school Biology I teachers were being transmitted to their students by way of instruction in biological evolution curriculum. Seventy-six teachers and 993 of their students participated in this study. To identify participants' misconceptions, calculate conception index scores, and collect demographic data, the *Biological Evolution Literacy Survey* (BEL Survey) was developed. The BEL Survey presents 23 biological misconception statements grouped into five categories. Analysis revealed teacher participants possessed a 72.9% mean rate of understanding of evolution concepts coupled with a 23.0% mean misconception rate whereas student participants possessed a pre-instruction 43.9% mean rate of understanding combined with a 39.1% mean misconception rate. Students exited the Biology I classroom more confident in their evolution knowledge but holding greater numbers of misconceptions than they possessed prior to entering the course. Significant relationships were revealed between students' acquisition of misconceptions and teachers' bachelor's degree field, terminal degree, and hours dedicated to instruction. One student misconception was revealed to be significantly more common following instruction as opposed to prior to instruction.

MANUSCRIPT I

A Regional Study of the Prevalence of Biological Evolution-related Misconceptions Held by Introductory Biology Teachers

This manuscript is prepared for submission to the peer-reviewed journal *Evolution: Education and Outreach* and is the first of three manuscripts prepared for a journal-ready doctoral dissertation.

Abstract

Biological evolutionary explanations pervade all biological fields and bring them together under one theoretical umbrella. Whereas the scientific community embraces the theory of biological evolution, the general public largely lacks an understanding, with many adhering to misconceptions. Because teachers are functioning components of the general public and most teachers experience the same levels of science education as does the general public, teachers too are likely to hold biological evolution misconceptions. The focus of this study was to identify the types and prevalence of biological evolution misconceptions held by Oklahoma high school introductory biology teachers and to correlate those findings with demographic variables. Seventy-six teachers who taught at least one section of Biology I during the 2010 – 2011 academic year in one of 71 Oklahoma public high schools served as this study's unit of analysis. The *Biological Evolution Literacy Survey* (Yates and Marek 2011) which possesses 23 biological misconception statements grouped into five categories, served as the research tool for collecting demographic data, identifying participants' misconceptions, and calculating conception index scores. Analysis of survey results revealed participants' knowledge of biological evolution concepts to be lacking as indicated by a mean 72.9% rate of understanding coupled with a 23.0% misconception rate. Results also indicated significant differences in participants' mean index scores related to biological evolution knowledge self-rating and hours dedicated to teaching evolution. Implications associated with the study's results are explained, including that of teachers serving as sources of student misconceptions.

Keywords: biology education, biology teachers, evolution education, misconception, Oklahoma, public high school

"The teacher of biology has an opportunity--and an obligation--to point out some of the practical implications of Darwinian theory . . . . A thoughtful biologist cannot fail to find (in Shakespeare's words) 'tongue in trees, books in the running brooks, sermons in stones . . . .' If he is interested in people as well as in things . . . he will want to help students hear the sermons" (Hardin 1973, p. 15).

Introduction

The most powerful theory within the biological sciences is evolution (Rutledge and Warden 2000). The theory of evolution's importance transcends categorization as simply another biological subtopic; rather, it is the unifying theme through which much of biology understanding must pass (Zook 1995). Biological evolutionary explanations pervade all fields in biology and bring them together under one theoretical umbrella (Colby 1996). This umbrella allows for the investigation, in a scientifically meaningful manner, of a broad spectrum of biological questions concerning the tremendous diversity of life on Earth. In the presence of biological evolutionary theory, the multitude of traits and behaviors of organisms take on meaning (Rutledge and Warden 2000) and in its absence, biological questions remain shrouded in mystery. So important is biological evolution theory to the field of biology that the eminent geneticist and evolutionary biologist Theodosius Dobzhansky titled his benchmark 1973 essay *Nothing in Biology Makes Sense Except in the Light of Evolution* (p. 125). Not only is a working knowledge of biological evolution instrumental in the field of biological sciences, biological evolution is one of the most important concepts in attaining scientific literacy (Alters and Alters 2001). Nelson (2008) pondered, ". . . what could have really been accomplished in a biology course if students left it without understanding evolution and the powerful evidence on which it is based?" (p. 223).

Although biologists continue to debate the mechanisms, patterns, and details of evolution (Pond and Pond 2010), within the biological community the evidence for evolution is paramount and beyond dispute with little argument that evolution has and is currently happening (American Association for the Advancement of Science [AAAS] 1989; Moore 2000; National Academy of Sciences [NAS] 1999; National Association of Biology Teachers [NABT] 2008; National Research Council [NRC] 1985; Nelson and Skehan 2000; Oklahoma Academy of Science 2007; Rutledge and Warden 1999). Thus, the scientific community regards evolution as a vital part of science education (National Academies of Science 2008). Scientific organizations, including the NAS (1999), NABT (2008), AAAS (2002), and the National Science Teachers Association (1997) support the teaching of the theory of evolution as a unifying theme in biological sciences.

Whereas the scientific community embraces the theory of biological evolution, the majority of the general public greets evolution with skepticism and a less than enthusiastic response. Public resistance to accepting evolution appears to have grown even as the strength of the evidence supporting evolution has increased markedly in the advancing molecular era of biology (Nelson 2008). In fact, over the past 20 years, the percentage of U. S. adults accepting the idea of evolution has declined (Miller et al. 2006). Miller (2006) indicated that probable reasons for society's low acceptance of evolution include the widespread lack of understanding of biological concepts. Gregory (2009) lamented, "The unavoidable conclusion is that the vast majority of individuals . . . lack a basic understanding of how adaptive evolution occurs" (p. 172). Not only does the general public largely lack an understanding of biological evolution (Abraham et al. 2009), such a lack of understanding has been implicated in high levels of biological evolution misconceptions within the populace (Alters and Alters 2001; Miller 1999, 2008). These misconceptions can range from minor misunderstandings to complete theory rejection (Alters and Alters 2001; Dagher and BouJaoude 2005; Evans 2001; Mazur 2004; McComas 2006; Sadler 2005).

Because teachers are functioning components of the general public, teachers too are likely to hold biological evolution misconceptions. Across the nation, this hypothesis is supported as: (a) significant percentages of high school teachers are not convinced that evolution is a central concept to biology (Osif 1997; Rutledge and Warden 2000; Tatina 1989; Weld and McNew 1999; Zimmerman 1987); (b) only 57% of biology teachers nationwide consider evolution to be a unifying theme in biology (Moore 2000); and (c) 30% reject the theory of evolution (Alters and Alters 2001). Since over a third of high school biology teachers are not biology majors (National Center for Educational Statistics 2005) and most teachers experience the same levels of science education as the general public, it is expected that they too will hold the same biological evolution misconceptions (Nadelson 2009).

Scientific understanding of biological evolution is complex and multifaceted (Gould 2002; Miller 1999); it is therefore not surprising that individuals who are not well-versed in the topic may hold misconceptions (Miller 1999). Trani (2004) contends that the gap between the scientific community and biology teachers' and laypersons' understanding and acceptance of the theory of evolution is large. Since high school biology teachers serve as an important link between scientists' and the general public's understanding and perception of biological evolution (Nehm and Schonfeld 2007), they should be prepared to present to their students the principles of evolutionary theory void of any misinterpretations or misconceptions.

In order to assess public high school introductory-biology teachers' conceptions and knowledge structure about biological evolution, we surveyed such teachers across a southern state as defined by the 2010 U. S. Census Bureau. The specific purpose of this study was to identify the types and prevalence of biological evolution-related misconceptions held by the study's participants and to correlate those misconceptions with known variables including: (a) gender, (b) years of teaching experience, (c) terminal degree, (d) bachelor's degree major, (e) emphasis given to biological evolution during teachers' college education, (f) teachers' self-rating of biological evolution knowledge, (g) hours dedicated to teaching biological evolution in the classroom, (h) urban-centric classification of teachers' schools of employment, and (i) average daily membership (ADM) of teachers' school of employment. Although we do not claim that the findings of this study, undertaken in a single southern state, are applicable nationwide, results obtained do contribute to the biological evolution misconception education literature and may be compared to similar studies which differ geographically and/or temporally.

Method

Context

As a criterion for inclusion in this study, participants must have taught at least one Biology I course section during the 2010-2011 academic year. Therefore, it was expected that participants possess accurate knowledge of those biological evolution-related concepts set forth by both national and state education standards as important for student acquisition. State science standards are the basis for what teachers teach and students learn and thereby establish the foundation for states' desired science education outcomes (Moore 2001). The state of Oklahoma has academic standards and assessments aligned to those standards. The Oklahoma State Department of Education's (OSDE) *Priority Academic Student Skills (PASS;* OSDE 2009a) were developed in 1993 based on the *National Science Education Standards* (*NSES*; NRC 1996) and the *Benchmarks for Scientific Literacy* by the AAAS (1993). *PASS* science standards present a framework for what students should know, understand, and be able to do in the natural sciences (NRC 1996). High school Biology I possesses several *PASS* content standards that emphasize biological evolution-related concepts of which teachers of the course should be thoroughly knowledgeable and should accurately teach to their students. The *Oklahoma End-of-Instruction Biology I Alignment Blueprint* (OSDE 2008-2009) calls for approximately 28 to 39% of the test to cover biological evolution-related concepts. These *PASS* biological evolution-related standards were a primary reference in the development of the teacher survey instrument employed in this study.

Participants

Participants in this study included 76 high school biology teachers (40 males and 36 females) employed on a full-time basis during the 2010-2011 academic year by 71 (15.0%) of the 474 public high schools (OSDE 2009b) located within the state of Oklahoma, which served as the study region. For the purposes of this study, a high school is defined as a secondary school offering any combination of grades 9 through 12. All teacher participants possessed a current state teaching license which was obtained by meeting state licensure criteria. These criteria included a minimum of a bachelor's degree and passing scores on state certification tests. All participants were certified to teach biological sciences within the state of employment and all teacher participants taught at least one Biology I course section at the high school level (typically 9th or 10th grade) during the 2010-2011 academic year. Each potential teacher participant who met the study's criteria and volunteered to participate was presented with an Informed Consent to Participate in a Research Study form approved by the researchers' university Office of Human Research Participant Protection.

Table 1 describes the teachers' profile. While all participants possessed bachelor's degrees, 38.1% (n = 29) held graduate degrees as well. Biology bachelor's degrees were held by 28.9% (n = 22) of the respondents while the remainder possessed either science education, nonbiology science, or nonscience bachelor's degrees. Prior to this study, 18.4% (n = 14) of the teacher participants had completed five or fewer years of teaching experience; 35.5% (n = 27) ten or fewer years of teaching experience; and, 27.6% (n = 21) had accumulated over 20 years of experience in the classroom.

Instrumentation

To identify teacher participants' misconceptions of biological evolution, an instrument was developed called the *Biological Evolution Literacy Survey* (BEL Survey; Yates and Marek 2011, p. 32-33). With permission, the BEL Survey was modeled after Cunningham and Wescott's 2009 survey which, in turn, was adapted from Almquist and Cronin (1988) with additions from Wilson (2001), and Bishop and Anderson (1986, 1990). The BEL Survey is composed of two sections. The first section requested demographic data which included gender, highest earned degree, degree major, years of teaching experience, current employment status (full-time or part-time), whether the participant was certified to teach biology at the secondary level, and primary teaching duty. In addition, this section asked teacher participants to rate the emphasis given to evolution education in their college courses, the number of hours the teacher dedicates to the teaching of biological evolution concepts in a single Biology I course section, and self-rating of biological evolution knowledge. The BEL Survey was completed in anonymity.

The second section of the BEL Survey asked teacher participants to respond to whether they strongly agree, somewhat agree, somewhat disagree, strongly disagree, or have no opinion (“undecided/or never heard of it”) on 23 statements related to biological evolution-related misconceptions. During data analysis, two methods of scoring responses were used. First, the responses “strongly agree” and “somewhat agree” were combined, indicating the participant agreed with the statement. Likewise, the responses “strongly disagree” and “somewhat disagree” were combined, indicating participant disagreement with the statement. Second, a biological evolution misconception scoring index for the statements was created by Likert scaling of responses with answers to statements indicative of a low acceptance of an evolution concept (high acceptance of the associated misconception) receiving low scores and answers to statements indicative of a high acceptance of an evolution concept (nonacceptance of misconception) receiving high scores. For statements in which agreement indicated nonacceptance of the associated misconception (statements 2, 4, 8, 10, 11, 14, 15, 18, 20, 23), index scoring was as follows: (a) strongly agree, score of 5; (b) somewhat agree, 4; (c) undecided/never heard of it, 3; (d) somewhat disagree, 2;

(e) strongly disagree, 1; and (f) no response, 0. For statements in which agreement indicated acceptance of the associated misconception (statements 1, 3, 5, 6, 7, 9, 12, 13, 16, 17, 19, 21, 22) index scoring was as follows: (a) strongly agree, 1; (b) somewhat agree, 2; (c) undecided or never heard of it, 3; (d) somewhat disagree, 4; (e) strongly disagree, 5; and (f) no response, 0. The possible range of BEL Survey index scores was 0 to 115 with a score of 115 representing the highest level of understanding of those evolutionary concepts revealed by the BEL Survey coupled with a lack of associated misconceptions whereas lower indices represented lower levels of understanding combined with higher levels of biological evolution-related misconceptions.

Cunningham and Wescott's (2009) survey instrument on which the BEL Survey is modeled contained 24 statements classified into four categories: (a) evolutionary theory, (b) scientific facts, (c) process of evolution, and (d) language of science. For the present study, Cunningham and Wescott's four-category classification was modified into five categories of biological evolution-related misconceptions that are commonly employed in the literature (e.g., Alters and Alters 2001; Bishop and Anderson 1990; Greene 1990; Gregory 2009; Jensen and Finley 1996; Wandersee, Mintzes and Novak 1994; Wescott and Cunningham 2005; Wilson 2001). These misconception categories include: (a) science, scientific methodology and terminology (SSMT); (b) intentionality of evolution (IE); (c) nature of evolution (NE); (d) mechanisms of evolution (ME); and (e) evidence supporting evolution (ESE). While five biological evolution-related misconception statements were identified or developed for each of the SSMT, IE, and ME categories, four such statements were identified or developed for each of the NE and ESE categories. The resulting 23 statements were subsequently included in the BEL

Survey (see Table 3) whereas category identification was omitted. Of the BEL Survey's 23 statements, two (11, 16) were taken directly from Cunningham and Wescott's survey; eight were adapted from Cunningham and Wescott's survey (statements 1, 6, 7, 9, 15, 17, 20, 22); and the remaining 13 statements (statements 2, 3, 4, 5, 8, 10, 12, 13, 14, 18, 19, 21, 23) were developed through an extensive search of biological evolution misconception literature. Cronbach's alpha of 0.848 was identified for the 23-statement BEL Survey which indicates that the internal reliability of the survey is acceptable. Additionally, if any one statement is deleted, the reliability coefficient does not decrease by more than 0.014, thus maintaining survey's internal reliability.

Results and Discussion

Table 1 presents the participant profile and the BEL Survey mean index score (BEL-MIS) for members of each identified criteria. Participants were comprised of 52.6% males (n = 40) and 47.4% females (n = 36). While all participants possessed a minimum bachelor's degree, 34.2% (n = 26) held terminal master's degrees with 3.9% (n = 3) earning doctorate degrees. Bachelor's degree majors were fairly evenly distributed among biology (28.9%, n = 22), science education (28.9%, n = 22), and nonbiology science degrees (23.7%, n = 18), while only 15.8% (n = 12) of participants possessed nonscience bachelor's degrees. Years of participant teaching experience were equally distributed between the 0 to 5, 6 to 10, 11 to 15, and 16 to 20 year categories with 17.1 to 18.4% (n = 13 to 14) of participants occupying each category. However, 27.6% of teachers (n = 21) had over 20 years of teaching experience prior to participating in the study. Approximately 62.0% (n = 47) of participants indicated that the emphasis placed on evolution in their college courses was either moderate (47.5%, *n* = 36) or high (14.5%, *n* = 11) while 36.8% (*n* = 28) revealed slight (28.9%, *n* = 22) or no emphasis (7.9%, *n* = 6). Participants were asked to rate themselves based on their knowledge of evolution. Sixty-seven percent (*n* = 51) judged their evolution knowledge to be either good (44.7%, *n* = 34) or excellent (22.4%, *n* = 17) while only 5.3% (*n* = 4) described their knowledge level to be fair or poor.

Significant Differences

Chi-square statistics were utilized to identify the existence of statistically significant differences ($p < .05$) among variables related to the 71 public high schools employing the study's 76 teacher participants and the sum total 474 public high schools located within the study area (see Table 2). A comparison between the two sets of schools focused on two variables: (a) distribution of student ADM (Institute of Education Sciences National Center for Educational Statistics [IESNCES] 2010a); and, (b) urban-centric classification (IESNCES 2010b). No statistically significant differences were revealed between the two high school groups for either ADM distribution, $\chi^2(4, N = 71) = 1.38$, $p > .05$, or urban-centric classification, $\chi^2(3, N = 71) = 7.05$, $p > .05$. These results indicate that the public high schools from which teacher participants originated were representative of the collective public high schools within the study area in terms of both ADM and urban-centric classification. A 10.74 confidence interval at a 95% confidence level was determined for the sample of high schools employing teacher participants (*n* = 71) compared to the total number of public high schools (*N* = 474) located within the study area.

Independent samples *t*-tests and one-way analysis of variance tests (ANOVA) were employed to determine if significant differences ($p < .05$) existed between participants' BEL-MIS when related to specific group variables. Group variables analyzed included gender, terminal degree, degree major, emphasis placed on evolution in teachers' college courses, years of teaching experience, hours dedicated to the teaching of biological evolution in a single Biology I course, self-rating of biological evolution knowledge, and teachers' schools of employment ADM and urban-centric classifications. BEL-MIS related to these specific variables are identified in Table 1. Female participants ($n = 36$) produced a 93.39 BEL-MIS while male participants ($n = 40$) produced a BEL-MIS of 87.48. Although females did average 5.91 index points (6.3%) higher than did their male counterparts, the difference was not statistically significant, $t(74) = 1.71$, $p = .42$.

BEL-MIS were calculated based on participants' schools of employment urban centric classification. No significant differences ($p < .05$) in participants' BEL-MIS were identified between the four urban-centric classifications, $F(3, 61) = .58$, $p = .63$. However, a trend was revealed showing a consistent increase in teachers' BEL-MIS as one moves from rural, to town, to suburban, to city urban-centric school locations. Although school location has been identified as an important predictor of evolution teaching practices (Donnelly and Boone 2007) and emphasis provided to evolution has been shown to be weaker in rural schools (Troost 1966, as cited in Donnelly and Boone 2007, p. 238), our results may not provide an accurate reflection due to the small number of study participants teaching in both suburban ($n = 3$) and city area schools ($n = 2$).

Participants' BEL-MIS were also calculated based on participant schools' ADM classification. ANOVA revealed no significant differences in participants' BEL-MIS when related to the five ADM classes of high schools, $F(4,60) = .38$, $p = .82$. The highest BEL-MIS (95.36, $n = 14$) belonged to those participants teaching in schools possessing an ADM which fell within the top 20% (4451.85-485.57) while the lowest BEL-MIS (88.54, $n = 13$) was produced by those participants who taught in schools possessing an ADM in the lowest 20% range (77.73-14.85). These results agree with previous studies indicating that emphasis provided to evolution is stronger in larger schools (e.g., Aguillard 1999; Shankar and Skoog 1993).

BEL-MIS based on participants' terminal degrees were identified. ANOVA revealed no significant differences ($p < .05$) between participants' BEL-MIS based on the terminal degree classes, $F(2, 73) = .54$, $p = .58$. In addition, BEL-MIS based on participants' bachelor's degree major were analyzed. Although no significant differences were identified between participants' BEL-MIS related to bachelor's degree major categories, $F(3,70) = 1.85$, $p = .15$, a relatively low nonsignificant difference ($p = .10$) was discovered between the BEL-MIS of those participants possessing nonscience bachelor's degrees (82.75, $n = 12$) and those possessing biology bachelor's degrees (95.45, $n = 22$). This result indicates to a relative degree that a public high school biology teachers' accurate knowledge of biological evolution concepts is at least partially related to their chosen bachelor degree major with a biology degree being the optimum choice of the four categories described. This finding is supported by Hoy, Davis, and Pape (2006), as well as Pajares (1992) who contend that teachers' understanding of content is nearly directly correlated with their education. Based on these results, bachelor degree major may play a role in the BEL-MIS difference between females ($M = 93.39$, $SD = 15.29$) and males ($M = 87.48$, $SD = 14.87$). Whereas

33.3% (*n* = 12) of females held biology bachelor's degrees and 13.9% (*n* = 5) held nonscience bachelor's degrees, 30.0% (*n* = 12) of males possessed biology bachelor's degrees while 20.0% (*n* = 8) held nonscience degrees.

Participants' BEL-MIS remained fairly consistent through the five classes of teaching experience, producing a range of only 2.62 index points (89.07 – 91.69). Although individual participants' biological evolution misconception index scores were not tracked throughout their teaching careers, this result seems to indicate that years of teaching experience does not significantly change a biology teacher's understanding of biological evolution conceptions as those participants with 0 to 5 years of experience (*n* = 14) produced an 89.07 BEL-MIS while those with over 20 years of teaching experience (*n* = 21) yielded only a slightly higher 90.95 BEL-MIS.

Participants were asked to identify the emphasis placed on biological evolution in their college courses as highly, moderately, or slightly emphasized, or not emphasized at all. Although no significant differences among participants' BEL-MIS when compared with the emphasis placed on biological evolution in their college courses were revealed, $F(3, 71) = 1.48$, $p = .23$, an upward trend does appear in BEL-MIS as emphasis is increased, leading one to surmise that the greater emphasis placed on biological evolution in the prospective biology teacher's college courses, the more accurate is the teacher's biological evolution concept knowledge. Those participants who indicated their college courses either highly or moderately emphasized biological evolution produced a 92.90 BEL-MIS (*n* = 47) whereas those participants who identified slight or no emphasis produced a somewhat lower 85.71 BEL-MIS (*n* = 28).

BEL-MIS based on the number of hours participants dedicated to the teaching of evolution in their Biology I course were identified and analyzed. A significant difference ($p < .05$) was revealed between the BEL-MIS of those participants who dedicated 0 hours of evolution instruction ($M = 77.00$, $SD = 0.0$, $n = 2$) and those who dedicated 6 to 10 hours ($M = 89.84$, $SD = 14.09$, $n = 19$) as well as between those who dedicated 0 hours of instruction and those who dedicated greater than 15 hours of instruction ($M = 99.86$, $SD = 15.79$, $n = 14$). This result reveals a positive correlation between teachers' index scores (i.e., biological evolution knowledge) and the number of hours dedicated to teaching evolution concepts in the public high school biology classroom.

Finally, BEL-MIS based on participants' self-rating of biological evolution knowledge were determined for the descriptors excellent, good, average, and fair. (Whereas *poor* was a fifth survey choice, this description was not selected by any participant). ANOVA revealed a significance difference in BEL-MIS among the biological evolution knowledge self-rating descriptor groups, $F(3, 72) = 2.81$, $p = .046$. Specifically, a significance difference of $p = .04$ was determined between the BEL-MIS for participants who indicated a good biological evolution knowledge rating ($M = 94.35$, $SD = 12.90$, $n = 34$) versus those who indicated a fair knowledge rating ($M = 80.75$, $SD = 12.96$, $n = 4$). This result implies a positive correlation between teachers' confidence in their biological evolution knowledge and the actual level of their knowledge. This finding should be interpreted as a general trend, however, as those participants who rated themselves as having an excellent knowledge of biological evolution ($n = 17$) claimed a BEL-MIS 2.17 index points lower ($M = 92.18$, *SD* = 20.34) than did those who identified themselves as possessing a good knowledge (*M* = 94.35, *SD* = 12.90, *n* = 34).

Science, Scientific Methodology and Terminology

Table 3 lists each BEL Survey statement and accompanying participant percent response. The combined percent responses of participants highlighted in gray identifies the percentage of participants who held the accompanying statement's associated misconception whereas the combined pair of percent responses in the adjacent nonhighlighted regions (either 1 and 2 or 3 and 4) identifies the percentage of participants who held the correct concept as related to the statement. Table 4 identifies interactions between participants' responses to selected statements. Statements 1 through 5 address the general opinions of participants concerning science, scientific methodology and terminology as they relate to evolutionary theory. Figure 1 illustrates the responses to each of these statements. Responses from statement 1 ("A scientific theory that explains a natural phenomenon can be defined as a 'best guess' or 'hunch'") reveals 77.6% ($n = 59$) of participants correctly interpreted the term *theory* as used in a scientific context whereas 18.4% ($n = 14$) failed to differentiate between the scientific concept of *theory* and its usage in common vernacular. Statement 5 ("Evolution cannot be considered a reliable explanation because evolution is only a theory") found that a somewhat lower percentage (72.3%, $n = 55$) correctly related the accurate definition of a scientific *theory* to the *theory of evolution*. Correlation analysis revealed a large positive correlation between the results for statements 1 and 5 with 83.0% ($n = 49$) of participants who disagreed with statement 1 ($n = 59$) also in disagreement with statement 5, $r(71) = .49$, $p < .01$. However, only 67.1% ($n = 49$) of participants who completed both statements 1 and 5 ($n = 73$) understand *theory* in the scientific context and correctly apply that meaning to the *theory of evolution*. Somewhat disturbingly, 15.3% (*n* = 9) of participants who appear to possess an accurate conception of a scientific *theory* (*n* = 59) contend that evolution cannot be considered a reliable explanation because evolution is *only a theory*. Of those participants who agreed with statement 1 (*n* = 14), 57.1% (*n* = 8) were consistent in their misconception by also agreeing with statement 5. For these participants the scientific use of *theory* does not differ from that of common usage (as in "best guess" or "hunch") and therefore evolution cannot be deemed reliable because it is *only a theory.* While disappointing, these findings are not surprising as the term *theory* is perhaps the most misunderstood word in science (Scott 2004). If teachers lack an understanding of the theory of evolution, they are less likely to present it in their class (Trani 2004) and, if the theory is presented, these findings imply a less than accurate depiction. In addition, teachers who possess misconceptions concerning scientific theories may view evolution as a weak science and indicate that evolution should be taught *only as a theory* and not as a fact (Bybee 2001; Nadelson 2009; Nehm and Schonfeld 2007).

Statement 2 ("The scientific methods used to determine the age of fossils and the earth are reliable") garnered 73.7% (*n* = 56) agreement among participants while 26.3% (*n* = 20) revealed their misconception. A comparative statement, statement 4 ("The Earth is old enough for evolution to have occurred"), received a slightly more favorable affirmation with 78.9% (*n* = 60) in agreement. A large positive correlation, $r(74) = .60$, $p <.01$), was discovered between participants' understanding of the reliability of dating techniques (statement 2) and the age of the Earth (statement 4) with 91.1% (*n* = 51) of participants who agreed with statement 2 (*n* = 56), also agreeing with statement 4. Presenting conflicting opinions of statements 2 and 4 were 18.4% (*n* = 14) of the participants with 13.2% (*n* = 10) disagreeing with statement 2 while agreeing with statement 4. While these individuals adhere to the misconception that scientific dating methods are not reliable, they do agree that the Earth is old enough for evolution to have occurred. Conversely, 7.1% (*n* = 4) agreed with statement 2 while at the same time disagreed with statement 4. Although these participants understand that scientific dating techniques are reliable they contend that the Earth is not old enough for evolution to have occurred.

A basic premise in evolutionary theory is the requirement of a large expanse of time over which evolutionary processes occur. Misconceptions conferring a young age to the Earth may lead individuals to the subsequent misconception that the Earth is not old enough for evolution to have occurred (Alters and Alters 2001; Smith and Sullivan 2007). This study revealed that 17.1% of participants (*n* = 13) contend that the Earth is not old enough for evolution to have occurred. This finding nearly replicates that of Berkman, Pacheco, and Plutzer, who in a 2008 study of 939 high school biology teachers discovered that one in six (16.7%) held young Earth views.

The response to statement 3 ("According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms") was somewhat less definitive. While it is encouraging that 56.6% (*n* = 43) of teachers lacked the associated misconception as evidence by their disagreement, nevertheless 21.1% (*n* = 16) were in agreement and a combined 22.3% (*n* = 17) either indicated *undecided/never heard of it* or failed to state an opinion. Of the BEL Survey's 23 statements, statement 3 generated the greatest percentage of *undecided/never heard of it* responses with 18.4% (*n* = 14).

Research reveals that teachers hold misconceptions related to the nature of science and how it pertains to the teaching of evolution (Moore and Kraemer 2005; Nadelson 2009; Nehm and Schonfeld 2007; Rudolph and Stewart 1998; Rutledge and Warden, 2002). This study's results concur with these findings as participants averaged a 71.8% rate of understanding, a 21.1% misconception rate, and a 7.1% combined undecided and nonresponse rate in response to the five *Science, Scientific Methodology and Terminology* survey statements. While 50.0% of participants (*n* = 35) who completed all five statements (*n* = 70) lack misconceptions related to any of the five statements, 17.1% (*n* = 12) held one misconception; 18.6% (*n* = 13) two misconceptions; 5.7% (*n* = 4) three misconceptions; 5.7% (*n* = 4) four misconceptions; and 2.9% (*n* = 2) held misconceptions related to each of the five statements. Collectively, 50.0% of participants held one or more misconceptions related to the *Science, Scientific Methodology and Terminology* category statements.

Intentionality of Evolution

Much of the human experience involves fulfilling needs as one attempts to overcome obstacles in order to achieve goals. Consequently there seems to be a powerful psychological bias toward imparting purpose or function to nonhuman objects, processes, and behaviors. Statements 6 through 10 address the general opinions of participants concerning the intentionality of evolution. Misconceptions associated with evolution intentionality subscribe a type of conscious will and directive to the mechanisms of evolution. Figure 2 illustrates the responses to each of these statements. Responses from statement 6 ("Evolution always results in improvement") reveal that 72.4% (*n* = 55) of participants disagreed with the statement and therefore correctly understand the process of evolution does not always result in improvement, while 25.0% (n = 19) agreed with the statement, thus disclosing an adherence to the misconception that evolution always does result in improvement. Statement 7 ("Members of a species evolve because of an inner need to evolve") produced comparable results with 73.7% (n = 56) in disagreement while 22.3% (n = 17) agreed, indicating that the majority of participants understand that evolution is not based on need. A large positive correlation, $r(72) = .378$, $p < .01$) exists between results for statements 6 and 7 with 79.6% (n = 43) of participants who disagreed with statement 6 (n = 54) also disagreeing with statement 7. For those participants that held to the misconception identified in statement 6 (n = 19), 36.8% (n = 7) also shared the misconception described in statement 7. This result indicates a tendency among these participants to view evolutionary processes as deterministic in nature with improvement as its goal, i.e., because species possess an inner need to evolve, evolution must always result in improvement.

Participant agreement with statement 9 ("If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation") also implies a deterministic view of evolutionary mechanisms. While 28.9% (n = 22) of participants did reveal such a misconception by agreeing with statement 9, the majority (69.7%, n = 53) were in disagreement. A medium positive correlation, $r(73) = 0.35$, $p < .01$, was unveiled between participants' responses to statements 6 and 9 with 54.7% (n = 41) of participants responding to both statements (n = 75) possessing neither misconception. For those participants who adhered to the misconception that evolution always results in improvement (statement 6), 42.1% (*n* = 8) compounded their commitment to evolutionary determinism by also sharing the misconception revealed in statement 9. Analysis revealed 32.0% (*n* = 24) of participants who answered both statements 6 and 9 (*n* = 75) possess contradictory conceptions in regard to intentionality of evolution as related to these statements.

Statement 10 ("Evolution cannot cause an organism's traits to change within its lifetime") produced 82.9% (*n* = 63) agreement among participants, with 13.2% (*n* = 10) in disagreement, and 3.9% (*n* = 3) undecided. These results indicate that the majority of participants correctly understand that evolutionary processes cannot produce change in an individual organism during its lifetime. Among those participants in agreement with statement 10, 87.5% (*n* = 49) also disagreed with statement 7 producing a medium negative correlation between the two, $r(73) = -.42$, $p < .01$, revealing that 65.3% (*n* = 49) of those participants who addressed both statements 10 and 7 (*n* = 75) correctly understand that evolution is not driven by need and cannot cause an organism's traits to change within its lifetime. However, of those participants who disagreed with statement 7, 10.7% (*n* = 6) also disagreed with statement 10. While these participants correctly understand that evolution is not need-driven, they hold the misconception that evolution can act upon an organism's traits during its lifetime. Disturbingly, 9.3% (*n* = 7) of participants possessing the misconception related to statement 7 also shared the misconception related to or were undecided concerning statement 10. This pattern of response discloses the mistaken idea that members of a species evolve because of an inner need to evolve and these needs can be fulfilled via the process of evolution during the lifetime of the organism.

Statement 8 (“Traits acquired during the lifetime of an organism--such as large muscles produced by body building--will not be passed along to offspring”) yielded agreement among 82.9% ($n = 63$) of participants, as opposed to 14.5% ($n = 11$) who held to the Lamarckian misconception of inheritance via acquired characteristics. A large positive correlation of $r(74) = .44$, $p < .01$ was discovered between participants’ responses to statements 8 and 10 (“Evolution cannot cause an organism’s traits to change within its lifetime”). Of those participants in agreement with statement 10 ($n = 62$), 88.7% ($n = 55$) also agreed with statement 8. These results indicate that the majority of participants correctly understand that characteristics acquired by an organism during its lifetime are not produced by evolutionary processes nor can acquired traits be passed along to the next generation. Of those participants disagreeing with statement 10 ($n = 10$), 60.0% ($n = 6$) agreed with statement 8 whereas 40.0% ($n = 4$) disagreed with statement 8. These 4 individuals, representing 5.3% of the participant population, not only adhere to the misconception that traits acquired during the lifetime of an organism can be passed on to offspring, but that such traits can be produced via evolutionary processes as well. Similarly, 4 participants of the 17 who agreed with statement 7 (“Members of a species evolve because of an inner need to evolve”) disagreed with statement 8. These individuals hold the two related misconceptions that evolution occurs as a response to need and traits acquired during the lifetime of an organism can be inherited by offspring.

While participants averaged a 76.3% rate of understanding in response to the five *Intentionality of Evolution* survey statements, a 20.8% misconception rate revealed several misconceptions. These misconceptions include: (a) evolutionary processes are deterministic with improvement as the goal, (b) species evolve because of an inner need to evolve, (c) evolution must always result in improvement, and (d) characteristics acquired during the lifetime of the organism can be inherited. Literature reveals that teachers are known to ascribe such teleological misconceptions to biological evolution (Jungwirth 1977; Tatina 1989; Zimmerman, 1987). When asked to describe the process of biological evolution, 27.0% of South Dakota high school biology teachers in Tatina's 1989 study and 22.0% of Ohio high school biology teachers in Zimmerman's study selected the phrase *purposeful striving*, revealing an adherence to misconceptions of biological evolution intentionality. Additionally, in a 2004 study of Brazilian secondary teachers ($N = 71$), 34.0% ($n = 24$) indicated that evolution always produces improvement (Tidon and Lewontin 2004) while in Nehm and Schonfeld's 2007 study, more than 25.0% of the high school science teacher participants ($N = 44$) adhered to the misconception that organisms' traits appear when needed. This study's results, which revealed a mean 20.8% intentionality of evolution misconception rate in participants, are comparable to the results obtained in the aforementioned studies conducted at differing locals, indicating that intentionality of evolution misconceptions are prevalent and consistent within the public secondary school biology teacher population regardless of geographical location.

While 43.2% ($n = 32$) of participants who completed all five statements ($n = 74$) lack misconceptions related to any of the statements, 25.7% ($n = 19$) held one misconception; 18.9% ($n = 14$) two misconceptions; 10.8% ($n = 8$) three misconceptions; and 1.4% ($n = 1$), four misconceptions. None of the participants possessed misconceptions related to each of the five statements. Collectively, 56.8% of participants held one or more misconception related to the intentionality of evolution.

Nature of Evolution

Participants' conceptions related to the nature of evolution, including the roles of randomness, the environment in evolutionary processes, and adaptation were addressed in statements 11 through 14. Figure 3 illustrates the responses to each of these statements. Responses from statement 11 ("New traits within a population appear at random") revealed the majority of participants (65.8%, $n = 50$) in agreement whereas 30.2% ($n = 23$) supported the misconception. Statement 13 ("Evolution is a totally random process") resulted in 32.9% ($n = 25$) of participants in agreement while 64.5% ($n = 49$) disagreed. A medium positive correlation of $r(74) = .36, p < .01$ between statements 11 (positive) and 13 (negative) reveals much diversity of opinion among participants, since only 40.8% ($n = 31$) were immune from at least one misconception for the combined statements. Of those participants in agreement with statement 11 who correctly identified that new traits appear in the population at random ($n = 50$), 44.0% ($n = 22$) agreed to the misconception that evolution is a totally random process. Additionally, of those participants who disagreed with statement 11 ($n = 23$), 13.0% ($n = 3$) agreed with statement 13. These individuals present the conflicting misconceptions that evolution is a totally random process yet new traits within a population do not appear at random.

Such a high misconception rate in teachers concerning the mechanism of randomness in evolution is disconcerting since there is probably no other misconception which better indicates a lack of understanding of evolution than the misconception that evolution proceeds by random chance (Isaak 2003). With the environment selecting specific variations within populations, evolution in totality is a nonrandom process. However, randomness does play a role in pivotal evolutionary mechanisms including the origination of variations via both mutations and gene recombination (Smith and Sullivan 2007). As Dawkins puts it, ". . . evolution is the nonrandom survival of randomly varying coded information" (The Wall Street Journal 2009, p. W2).

Statement 14 ("The environment determines which traits are best suited for survival") found a large majority of participants (89.5%, n = 68) in agreement while 9.2% (n = 7) disagreed. Of those participants agreeing with statement 11("New traits within a population appear at random"), 94.0% (n = 47) also agreed with statement 14 indicating that 61.8% (n = 47) of all participants correctly understand these two major premises of natural selection. However, 28.9% (n = 22) of participants held to one misconception while 4.0% (n = 3) revealed misconceptions associated with both statements 11 and 14. Analysis revealed 57.9% of participants (n = 44) holding correct conceptions for both statements 13 and 14. For those participants agreeing with statement 13 (n = 25), 92.0% (n = 23) also agreed with statement 14. While these participants understand that the environment plays a key role in determining which traits are best suited for survival they hold the contradictory view that evolution is a totally random process. Conversely, of those individuals who rightly disagreed with statement 13 (n = 49), 8.2% (n = 4) also disagreed with statement 14. For these participants, evolution is not a totally random process, yet the environment does not play a role in trait survivability.

Statement 12 ("Individual organisms adapt to their environments") found 55.2% (n = 42) of participants disagreeing whereas 44.7% (n = 34) were in agreement and therefore possessed the misconception. Of those in disagreement with statement 12 (*n* = 42), 92.9% (*n* = 39) were in agreement with statement 14 ("The environment determines which traits are best suited for survival"), correctly conferring the role of adaptation to the environment rather than to the individual organism. However, these participants (*n* = 39) represent only 51.3% of the total number of participants who responded to both statements 12 and 14 (*n* = 76). Of those individuals disagreeing with statement 12, 7.1% (*n* = 3) disagreed with statement 14 as well. For these participants, individual organisms do not adapt to their environments yet the environment fails to play a role in determining the survivability of traits and hence the development of adaptations. Of those participants agreeing with statement 12 (*n* = 34), 85.3% (*n* = 29) also agreed with statement 14. This group of participants assign to individual organisms the ability to adapt to their environments while the environment, in turn, determines which traits are best suited for survival. Not surprisingly, with statements 12 and 14 producing multiple combinations of responses replete with multiple combinations of misconceptions among participants, a very small negative correlation resulted, $r(27) = -.09$, $p < .41$.

Collectively, participants averaged a 68.7% rate of understanding, a 29.3% misconception rate, and a 2.0% combined undecided and nonresponse rate in response to the four *Nature of Evolution* survey statements. Only 23.7% (*n* = 18) of participants who completed all four statements (*N* = 76) lacked misconceptions related to any of the four statements, while 42.1% (*n* = 32) held one misconception; 27.6% (*n* = 21), two misconceptions; and 6.6% (*n* = 5), three misconceptions. None of the participants held misconceptions related to all four statements. Collectively, 76.3% of participants

(n = 58) held one or more misconception related to the four mechanisms of evolution statements.

Mechanisms of Evolution

Statements 15 through 19 address the opinions of participants concerning mechanisms that lead to evolutionary change. Figure 4 illustrates the responses to each of these statements. Responses from statement 15 ("Variation among individuals within a species is important for evolution to occur") found the majority of participants (88.2%, n = 67) in agreement whereas 9.2% (n = 7) assume the misconception that variation among members of a species is not an important contributing factor to evolutionary processes. Statement 19 ("Only beneficial traits are passed on from parent to offspring") fared slightly better with 92.1% (n = 70) in disagreement while 7.9% (n = 6) agreed and therefore incorrectly credited hereditary mechanisms in transmitting only beneficial traits from generation to generation. Of those participants agreeing with statement 15 (n = 67), 97.0% (n = 65) disagreed with statement 19 which contributed to a large negative correlation between the two statements, $r(74) = -.45$, $p < .01$. Analysis revealed 3.9% (n = 3) of participants disagreed with statement 15 while simultaneously agreeing with statement 19. While these participants believe variation among individuals within a species is not important for evolution to occur, at the same time they contend that only beneficial traits are passed from parent to offspring. Of those participants agreeing with statement 15 (n = 67), 23.9% (n = 16) also agreed with statement 9 ("If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation"). These teachers grasp the importance of variation in evolutionary change, yet they fail to understand completely those mechanisms which contribute to variation within a population.

Of those participants (*n* = 55) disagreeing with statement 6 ("Evolution always results in improvement"), 94.5% (*n* = 52) also disagreed with statement 19. These individuals, representing 68.3% of those participants responding to both statements (*n* = 75), correctly understand that evolution does not always result in improvement as beneficial traits are not the sole product of inheritance. Of those individuals agreeing with statement 6 (*n* = 19), 84.2% (*n* = 16) disagreed with statement 19. While these individuals inaccurately view evolution as a process which always results in improvement, they too disagree that only beneficial traits are passed from generation to generation. Three individuals, representing 3.9% of responding participants, agreed with both statements 6 and 19. For these participants, only beneficial traits are passed from parent to offspring, necessitating that evolution always results in improvement.

Participants' responses to statement 16 ("'Survival of the fittest' means basically that 'only the strong survive'") were somewhat split with 40.8% (*n* = 31) agreeing with the misconceptions as opposed to 59.2% (*n* = 45) who held the correct conception. For those individuals agreeing with statement 15 (*n* = 67), 62.7% (*n* = 42) disagreed with statement 16, resulting in a small negative correlation of $r(74) = -.23$, $p < .05$. Of those participants disagreeing with statement 15 (*n* = 7), 85.7% (*n* = 6) agreed with statement 16. This pair of misconceptions, evident in 7.9% (*n* = 6) of participants (*N* = 76), is indicative of faulty understanding of both the role of variation in evolution and its relationship to fitness. Confusion concerning *fitness* is not surprising as *survival of the fittest* is the most commonly used phrase drafted into everyday speech from the theory of evolution (Smith and Sullivan 2007) and, like the term *adapt*, the scientific meaning of *fitness* has no doubt been contorted by its use in common vernacular (see Alters and Nelson 2002; Bishop and Anderson 1990). Individuals have been known to commonly identify the meaning of survival of the fittest in direct relationship to physical strength, speed, intelligence or longevity (Anderson et al. 2002; Bishop and Anderson 1990; Robbins and Roy 2007) or even the number of mates possessed (Anderson et al.) as opposed to Darwin's definition: "[The] preservation of favourable individual differences and variations, and the destruction of those which are injurious" (1872, p. 63).

Statement 17 ("The size of the population has no effect on the evolution of a species") resulted in disagreement among 89.4% (n = 68) of participants while 9.2% (n = 7) voiced their approval for the statement, revealing their misconception. A medium negative correlation of $r(74) = -.27$, $p < .05$ was discovered between responses to statements 15 and 17 with 92.5% of those participants in agreement with statement 15 (n = 67) disagreeing with statement 17 (n = 62). These participants understand that variation among individuals within a species and population size are both contributing factors to evolution, however, the correlation does not reveal whether participants correctly understand the relationship between population size and variation within a population. There is little doubt that 7.5% (n = 5) of those participants in agreement with statement 15 (n = 67) fail to understand the relationship between population size and variation within a population as they were also in agreement with statement 17. While these individuals understand the role of variation in evolutionary processes, they fall short in understanding the contribution of population size. Likewise, a failure to grasp the relationship between variation and population size can be said of those participants who disagreed with statement 15 (*n* = 7) and either agreed (*n* = 2) or disagreed (*n* = 5) with statement 17.

Statement 18 ("Complex structures such as the eye could have been formed by evolution") drew a mixed response, being favored by only 56.6% (*n* = 43) of participants while 43.4% (*n* = 33) were in disagreement (36.8%, *n* = 28) or were undecided (6.6%, *n* = 5). This result leads one to conclude that while a teacher may have an adequate understanding of the mechanisms of evolution, they may not apply that understanding in all situations. A large positive correlation exists between the responses to statements 15 and 18, $r(74) = .41$, $p < .01$. Of those participants in agreement with statement 15 (*n* = 67), 62.7% (*n* = 42) also agreed with statement 18 revealing the majority of participants correctly understand that variation among individuals within a species is important for evolution to occur and that complex structures such as the eye could have been formed by evolution. Of those participants agreeing with statement 15 (*n* = 67) however, 32.8% (*n* = 22) disagree with statement 18 indicating that while these individuals understand that variation within a species is important for evolution to occur, they apparently disregard the role of variation within a population as an evolutionary tool contributing to the formation of complex structures. For those individuals in disagreement with statement 15 (*n* = 7), 71.4% (*n* = 5) disagreed with statement 18 as well. These individuals, which represent 6.6% of participants, not only fail to grasp the importance of variation in the evolution of complex structures but likewise discount the idea that complex structures could be produced via evolution.

Participants averaged a 77.1% rate of understanding, a 20.8% misconception rate, and a combined 2.1% undecided and nonresponse rate in response to the five *Mechanisms of Evolution* statements. While 36.8% (*n* = 28) of participants who completed all five statements (*n* = 76) lack misconceptions related to any of the five statements, 36.8% (*n* = 28) held one misconception; 14.5% (*n* = 11), two misconceptions; 7.9% (*n* = 6), three misconceptions; and 3.9% (*n* = 3), four misconceptions. None of the participants held misconceptions related to each of the five statements. Collectively, 63.2% of participants (*n* = 48) held one or more misconceptions related to the mechanisms of evolution statements.

Evidence Supporting Evolution

Statements 20 through 23 address the opinions of participants concerning evidence supporting evolution. Figure 5 illustrates the responses to each of these statements. Responses from statement 20 ("There exists a large amount of evidence supporting the theory of evolution") revealed the majority of participants (64.5%, *n* = 49) in agreement whereas 31.6% (*n* = 24) adhere to the misconception. These results vary somewhat from those of Rutledge and Warden's (2000) whose study of Indiana public high school biology teachers (*N* = 522) revealed a 77.0% agreement with their survey statement "There is a considerable body of data which supports evolutionary theory" (p. 25, Table 1). Although both statements measured the same concept, the 12.5 percentage point difference between the two results may be attributed to several factors, including the difference in the population sample sizes (*N* = 76 vs. *N* = 552) and/or statement terminology, i.e., "evidence" vs. "data".

Although evidence indicates that dinosaurs and humans are separated by approximately 65,000,000 years (Alters and Alters 2001; Alters and Nelson 2002) 25.0% (n = 19) of participants agreed with statement 22 ("Scientific evidence indicates that dinosaurs and humans lived at the same time in the past"). Adherence to this one misconception alone reveals a less than adequate understanding of the evidence supporting evolution. Study participants who hold this misconception are not alone however; this misconception has been previously disclosed in teachers (Nehm and Schonfeld 2007). A medium negative correlation of $r(73) = -.26$, $p < .05$ was produced between statements 20 and 22 with 81.2% (n = 39) of participants in agreement with statement 20 (n = 48) also in disagreement with statement 22. Of the participants agreeing with statement 20, 18.8% (n = 9) were either in agreement with (14.6%, n = 7) or were undecided (4.2%, n = 2) concerning statement 22. Although these participants (n = 9) are aware of the abundance of evidence supporting the theory of evolution, they are unaware, or choose to ignore, the evidence indicating the great expanse of time between the extinction of dinosaurs and the appearance of humans on the planet. Perhaps this particular result stems from the belief that the Earth is of a young age, therefore negating such an immense partition of time between dinosaur and human existence. Following correlation of these participants' responses to statements 20 and 22 with statement 4 ("The Earth is old enough for evolution to have occurred") however, this hypothesis is not supported as 100% of these participants (n = 9) either state the opinion that the Earth is old enough for evolution to have occurred (89.9%, n = 8) or are undecided on the topic (11.1%, n = 1). Of those participants who disagreed with statement 20 (n = 24) and therefore do not claim a large amount of evidence exists supporting evolution, 41.7% (n = 10) agree with statement 22, contending that scientific evidence indicates that dinosaurs and humans were contemporaries. These 10 individuals, holding to misconceptions associated with both statements 20 and 22, represent 13.3% of participants who responded to both statements (n = 75). Conversely, 50.0% (n = 12) of individuals disagreeing with statement 20 (n = 24) also disagreed with statement 22. Although these participants (n = 12) possess a misconception concerning the evidence supporting evolutionary theory, they disavow dinosaurs and humans living at the same point in time.

Correlation coefficients were produced between statement 20 and statements 2 (“The scientific methods used to determine the age of fossils and the Earth are reliable”) and 4 (“The Earth is old enough for evolution to have occurred”). Statements 20 and 2 revealed a large positive correlation of $r(74) = .47$, $p < .01$ with 57.9% (n = 44) of participants agreeing with both positive statements and 17.1% (n = 13) in disagreement with both statements. For this later group of participants, the failure to accept the existence of a large amount of evidence supporting the theory of evolution may, at least partially, be a direct result of their questioning the reliability of scientific dating methods. A large positive correlation, $r(74) = .61$, $p < .01$, was discovered between participants’ responses to statements 20 and 4 with 63.2% (n = 48) agreeing with both positive statements whereas 15.8% (n = 12) disagreed with both statements. For those participants adhering to misconceptions associated with both statements 20 and 4, 66.7% (n = 8) also held to the misconception identified by statement 2. These 8 individuals, representing 10.5% of all participants, are consistent in their multiple misconceptions, denying the large volume of evidence supporting the theory of evolution while asserting that scientific dating methods are not reliable and the Earth is not old enough for evolution to have occurred.

While scientific evidence informs us that humans and modern apes evolved in present-day Africa from common primate ancestors some six million years ago (Smith and Sullivan 2007), a common misconception concerning human origins is addressed in statement 21 ("According to the theory of evolution, humans evolved from monkeys, gorillas, or apes"). Analysis revealed 22.4% (n = 17) agreeing with statement 21 whereas 73.7% (n = 56) disagreed. The misconception that humans evolved from monkeys has been previously identified in teachers (Lord and Marino 1993; Sinclair and Pendarvis 1998). A small negative correlation of $r(74) = -.18$, $p = .13$ exists among the responses for statements 20 ("There exists a large amount of evidence supporting the theory of evolution") and 21. For those participants agreeing with statement 20 (n = 49), 79.6% (n = 39) disagreed with statement 21 indicating these individuals possess an accurate interpretation of both concepts. These 39 participants represent only 52.0% of all participants who responded to both statements 20 and 21(n = 75), revealing a relatively high percentage of participants (41.3%, n = 31) who possessed either one or both misconceptions related to this pair of statements. Of those participants agreeing with statement 20 (n = 49), 14.3% (n = 7) also agreed with statement 21. These participants indicate accurate knowledge of the extent of evidence supporting the theory of evolution yet they hold the misconception that humans evolved from monkeys, gorillas, or apes through evolutionary processes. Similarly, of those participants who disagreed with statement 20 (n = 24), 58.3% (n = 14) also disagreed with statement 21. While these individuals fail to recognize the abundant evidence supporting evolution, they correctly assert that humans did not evolve from monkeys, gorillas, or apes. Finally, of those participants who disagree with statement 20 (n = 24), 41.7% (n = 10) agree with statement 21 which indicates that these individuals hold misconceptions associated with both statements 20 and 21.

Statement 23 ("The majority of scientists favor evolution over other explanations for life") yielded 76.3% (n = 58) agreement among participants with 14.4 (n = 11) in disagreement. Of those participants who agreed with statement 20 (64.5%, n = 49), 79.6% (n = 39) also agreed with statement 23 while 20.4% (n = 10) either disagreed (12.2%, n = 6) or were undecided or never heard of it (8.2%, n = 4) statement 23. Thus, analysis revealed a medium positive correlation of $r(74) = .26, p < .05$ between statements 20 and 23. It is interesting that six participants who correctly indicate the existence of a large amount of evidence supporting evolution (statement 20) hold the misconception that the majority of scientists do not favor evolution over other explanations for life (statement 23). In addition, of those participants disagreeing with statement 20 (n = 24), 75.0% (n = 18) agreed with statement 23. These participants voiced the opinion that a large amount of evidence supporting evolution is lacking while at the same time believe the majority of scientists favor evolution over other explanations for life. These two contradictory results seem to indicate a lack of understanding of the process of science in these 24 individuals who total 31.6% of the teachers responding to both statements 20 and 23 (N = 76).

Although scientific evidence supporting biological evolution theory is abundant, diverse, and compelling, ranging from the homology of DNA to the fossil record (Alters and Alters 2001; Futuyma 1998; Ridley 1996; Shermer 2006), previous research has shown that many teachers doubt the scientific validity of evolutionary theory and state that evolution is not supported by available evidence (Nehm and Schonfeld 2007; Rutledge and Warden 2002). These findings are reflected in this study as participants earned a meager 70.7% mean rate of understanding in response to the four *Evidence Supporting Evolution* statements (statements 20 – 23) contained within the BEL Survey while producing a 23.4% misconception rate. While 41.3% (*n* = 31) of participants who completed all four statements (*n* = 75) lack misconceptions related to any of the four statements, 33.3% (*n* = 25) held one misconception; 13.3% (*n* = 10), two misconceptions; and 12.0% (*n* = 9), three misconceptions. None of the participants held misconceptions related to each of the four statements. Collectively, 57.9% of participants (*n* = 44) held one or more misconceptions related to the four *Evidence Supporting Evolution* statements.

Summary

This study's teacher participants (*N* = 76) earned a 90.28 (*SD* = 15.26) BEL-MIS for the 23 BEL Survey statements while expressing an average 72.9% rate of understanding, 23.0% misconception rate, and combined 4.1% undecided and nonresponse rate. Out of a possible maximum index score of 25.0, the *Science, Scientific Method and Terminology* category of five statements produced a BEL-MIS of 19.30 (*SD* = 5.07) coupled with a 71.8% rate of understanding and 21.1% misconception rate; *Intentionality of Evolution* category, a 20.33 (*SD* = 4.04) BEL-MIS, 76.3% rate of understanding, and 20.8 misconception rate; and *Mechanisms of Evolution* category, a 20.25 (*SD* = 4.11) BEL-MIS, 77.1% rate of understanding, and 20.8 misconception rate. Out of a possible maximum index score of 20.0, the *Nature of*

Evolution category produced a BEL-MIS of 14.80 (*SD* = 2.90) with a 68.7% rate of understanding and a 29.3% misconception rate, while the *Evidence Supporting Evolution* category yielded a BEL-MIS of 15.59 (*SD* = 3.62) with a 70.7% rate of understanding and a 23.4% misconception rate. Disturbingly, a minimum of 30.0% ($n \geq 23$) of the teachers did not accept the following:

1. New traits within a population appear at random (statement 11, 30.2%, *n* = 23).
2. Individual organisms do not adapt to their environments (statement 12, 44.8%, *n* = 34).
3. Evolution is not a totally random process (statement 13, 32.9%, *n* = 25).
4. "Survival of the fittest" does not mean that "only the strong survive" (statement 16, 40.8%, *n* = 31).
5. Complex structures such as the eye could have been formed by evolution (state ment18, 36.8%, *n* = 28).
6. There exists a large amount of evidence supporting the theory of evolution (statement 20, 31.6%, *n* = 24).

This study's results are consistent with those previously obtained in similar studies involving high school biology teachers' understanding of evolutionary theory and the nature of science. In a study with comparable participant numbers, Trani (2004) found levels of understanding at 83.4% for the theory of evolution and 77.7% for the nature of science among Oregon public high school biology teachers (*N* = 80). In a study of Indiana public high school biology teachers (*N* = 522), Rutledge and Warden (2000) discovered teachers possessed only a moderate level of understanding of evolutionary theory, correctly answering a mean 14.89 (*SD* = 4.05) items on a 21 item scale for a 70.9% correct rate of response.

Conclusion

Rutledge and Warden (2000) ventured the question: “What is the state of acceptance and understanding of evolutionary theory among biology teachers—those charged with teaching this most powerful and unifying idea and fostering scientific literacy among the populace?” (p. 23). By means of the BEL Survey, this study set out to answer this question in part by assessing the biological evolution conception and knowledge structure held by Oklahoma public high school introductory biology teachers. If these collective participants (*N* =76) were graded for their efforts, they would “earn” a low C based on their 72.9% rate of understanding across the five categories of biological evolution statements coupled with a 23.0% misconception rate.

There are several implications associated with the results of this study. First, teaching evolution comes down to the classroom biology teacher and personal decision making (Goldston and Kyzer 2009). Research reveals that teachers’ attitudes and views about subject matter impacts their decisions related to curriculum and instruction (Carlesen 1991; Grossman 1989; Hashweh 1987; Shulman 1986; Wilson, Shulman and Richert 1987). According to Mumby (1984), teachers see the world through a personal perspective and modify the curriculum according to their own interpretation. A biology teacher’s attitudes and views will be tainted by the possession of misconceptions which, in turn, may affect the position of evolution as a scientifically valid explanation in the biology curriculum, even to the point of exclusion. If teachers do not understand the theory of evolution, they are less likely to include evolution in their classes (Trani 2004). As Rutledge and Mitchell note (2002):

> As teachers are critical determiners of the quality of classroom instruction, it is vital that they be capable of making professionally responsible instructional and curricular decisions. For biology teachers to make such decisions about evolution, they must possess a thorough knowledge of evolutionary theory and its powerful role in the discipline of biology. (p. 25)

Second, when teachers hold science misconceptions, they may critically impede student conceptual development of scientific explanations (Crawford et al. 2005; Fisher 2004; Jarvis et al. 2003; Kikas 2004). Teachers with misconception-laced subject knowledge will convey inaccurate or incomplete ideas to their students, resulting in a less than accurate biological evolution education, likely fraught with errors. Because student knowledge structures have been found to approximate those of their teachers (Diekhoff 1983) and teachers frequently subscribe to the same misconceptions as their students (Wandersee et al. 1994), teachers' conception and knowledge structure of evolution will no doubt impact student understanding of this powerful and unifying idea (Rutledge and Mitchell 2002). An additional consequence of teacher-held misconceptions is the reinforcement of student-held misconceptions via instruction. Wescott and Cunningham (2005) contend that those evolution-related misconceptions students possess prior to instruction are "deeply rooted, extremely complex, and frequently reinforced by a number of sources including instructors" (p. 1). Further, teacher-held misconceptions of evolutionary theory may hinder the ability for the teachers themselves to learn new concepts or may actually lead to the development of additional or more complex misconceptions (Alters 2004; McComas 2006; Miller 1999) which in turn will have even more negative impact on student instruction.

Finally, the formation of misconceptions by students may be attributed to misconceptions passed along from teachers (Yip 1998). There is evidence indicating that many science misconceptions may actually have been taught to students by their teachers (Alters and Nelson 2002; Driver et al. 1994; Fisher 2004) and several studies suggest that many biology teachers, even those with experience, show misunderstanding of various biological concepts and that such misconceptions may be conveyed to their students (e.g., Barrass 1984; Sanders 1993; Yip 1996). It is argued that for certain areas in biology, particularly those that are concerned with more complex or abstract phenomena such as evolution, individuals are less likely to come into immediate and direct contact with them in daily life, so they have little chance to develop their own naïve understandings or misconceptions (Lawson 1988). Therefore, teachers may be a primary factor in the acquisition, propagation, and perpetuation of students' biological evolution-related misconceptions. Certainly, additional research is warranted in this area which has prompted us to extend our current research to address the question: Do biology teachers teach their students misconceptions of biological evolution? Results will be forthcoming.

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Table 1

Teacher Profile

Demographic Variable	Variables	*n*	%*	BEL-MIS
Gender	Female	36	47.4	93.39
	Male	40	52.6	87.48
Highest earned degree	Bachelor's	47	61.8	90.00
	Master's	26	34.2	89.73
	Doctorate	3	3.9	99.33
Bachelor's degree major	Biology	22	28.9	95.45
	Nonbiology science	18	23.7	90.22
	Science education	22	28.9	90.04
	Nonscience	12	15.8	82.75
	No response	2	2.6	-
Years teaching experience	0 – 5	14	18.4	89.07
	6 – 10	13	17.1	91.69
	11 – 15	14	18.4	90.71
	16 – 20	14	18.4	88.71
	> 20	21	27.6	90.95
College evolution emphasis	Highly emphasized	11	14.5	91.64
	Moderately emphasized	36	47.4	93.31
	Slightly emphasized	22	28.9	86.68
	Not emphasized	6	7.9	82.17
Knowledge self-rating	Excellent	17	22.4	92.18
	Good	34	44.7	94.35_a
	Average	21	27.6	83.95
	Fair	4	5.3	80.75_a
	Poor	0	0.0	-

Table 1 (continued).

Demographic Variable	Variables	*n*	%*	BEL-MIS
Teaching hours dedicated	0	2	2.6	77.00_{bc}
	1 – 5	27	35.5	86.56
	6 – 10	19	25.0	89.84_{b}
	11 – 15	13	17.1	89.08
	> 15	14	18.4	99.86_{c}
	No response	1	1.3	-
Average daily membership	4451.85 – 485.57	14	18.4	95.36
	482.10 – 242.95	18	23.7	91.78
	242.30 – 134.10	9	11.8	93.22
	132.10 – 78.11	11	14.5	91.55
	77.73 – 14.85	13	17.1	88.54
	No response	11	14.5	-
Urban-centric classification	City	2	2.6	103.50
	Suburban	3	4.0	96.33
	Town	19	25.0	92.53
	Rural	41	53.9	90.98
	No response	11	14.5	-

Note. BEL-MIS = BEL Survey mean index score. Maximum index score is 115. Those BEL-MIS possessing the same subscript are significantly different at $p < 0.05$.

*Percentages may not total 100 due to rounding.

Table 2

Public High School Profile

Demographic variable	Variable range	Percentage of High Schools	
		Participant HS (N =71)	Study Area HS (N = 474)
Average daily membership*[a]	4451.85 – 485.57	20.0	20.0
	482.10 – 242.95	23.3	20.0
	242.30 – 134.10	16.7	20.0
	132.10 – 78.11	18.3	20.0
	77.73 – 14.85	21.7	20.0
Urban-centric classification*[b]	City	3.3	7.2
	Suburban	5.0	5.7
	Town	26.7	17.7
	Rural	65.0	69.4

Note. *HS* = high school. Participant high schools employ study participants whereas study area high schools are the total number of high schools within the study area.

[a]Average daily membership (ADM) is the aggregate membership of a school during a reporting period (normally a school year) divided by the number of days school is in session during this period (IESNCES, 2010a).

[b]Urban-centric classification (IESNCES, 2010b)

*p >.05. Difference is not significant.

Table 3

BEL Survey Statement Percent Teacher Response

#	Category	Statement	Teacher % Response*					
			1	2	3	4	5	6
1	SSMT1	A scientific theory that explains a natural phenomenon can be classified as a "best guess" or "hunch"[a]	2.6	15.8	10.5	67.1	1.3	2.6
2	SSMT2	The scientific methods used to determine the age of fossils and the earth are reliable.	39.5	34.2	14.5	11.8	0.0	0.0
3	SSMT3	According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms.	13.2	7.9	25.0	31.6	18.4	3.9
4	SSMT4	The earth is old enough for evolution to have occurred.	60.5	18.4	3.9	13.2	3.9	0.0
5	SSMT5	Evolution cannot be considered a reliable explanation because evolution is only a theory.	7.9	14.5	19.7	52.6	3.9	1.3
6	IE1	Evolution always results in improvement. [a]	10.5	14.5	25.0	47.4	1.3	1.3
7	IE2	Members of a species evolve because of an inner need to evolve.[a]	10.5	11.8	13.2	60.5	2.6	1.3
8	IE3	Traits acquired during the lifetime of an organism--such as large muscles produced by body building--will not be passed along to offspring.	71.1	11.8	6.6	7.9	2.6	0.0
9	IE4	If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation. [a]	9.2	19.7	15.8	53.9	1.3	0.0

Table 3 (continued).

#	Category	Statement	Teacher % Response*					
			1	2	3	4	5	6
10	IE5	Evolution cannot cause an organism's traits to change within its lifetime.	73.7	9.2	7.9	5.3	3.9	0.0
11	NE1	New traits within a population appear at random.[b]	35.5	30.3	19.7	10.5	3.9	0.0
12	NE2	Individual organisms adapt to their environments.	23.7	21.1	11.8	43.4	0.0	0.0
13	NE3	Evolution is a totally random process.	13.2	19.7	23.7	40.8	2.6	0.0
14	NE4	The environment determines which traits are best suited for survival.	52.6	36.8	5.3	3.9	1.3	0.0
15	ME1	Variation among individuals within a species is important for evolution to occur.[a]	73.7	14.5	6.6	2.6	2.6	0.0
16	ME2	"Survival of the fittest" means basically that "only the strong survive."[b]	10.5	30.3	14.5	44.7	0.0	0.0
17	ME3	The size of the population has no effect on the evolution of a species[a]	5.3	3.9	27.6	61.8	1.3	0.0
18	ME4	Complex structures such as the eye could have been formed by evolution.	34.2	22.4	10.5	26.3	6.6	0.0
19	ME5	Only beneficial traits are passed on from parent to offspring.	3.9	3.9	14.5	77.6	0.0	0.0
20	ESE1	There exists a large amount of evidence supporting the theory of evolution.[a]	46.1	18.4	13.2	18.4	3.9	0.0
21	ESE2	According to the theory of evolution, humans evolved from monkeys, gorillas, or apes.	13.2	9.2	9.2	64.5	3.9	0.0
22	ESE3	Scientific evidence indicates that dinosaurs and humans lived at the same time in the past.[a]	9.2	15.8	7.9	59.2	6.6	1.3

Table 3 (continued).

#	Category	Statement	Teacher % Response*					
			1	2	3	4	5	6
23	ESE4	The majority of scientists favor evolution over other explanations for life.	51.3	26.3	11.8	2.6	7.9	0.0

Note: *SSMT* = science, scientific methodology and terminology; *IE* = intentionality of evolution; *NE*= nature of evolution; *ME* = mechanisms of evolution; *ESE*= evidence supporting evolution; *1* strongly agree; *2* somewhat agree; *3* somewhat disagree; *4* strongly disagree; *5* undecided/never heard of it; *6* no response. Shaded areas indicate percentage of participants accepting the statement-related misconception.

*Percent response may not total 100.0% due to rounding.

[a]Statement adapted from Cunningham and Wescott (2009).

[b]Statement taken directly from Cunningham and Wescott (2009).

Table 4

Interaction Between Teacher Responses to Selected BEL Survey Statements

Statement	Interaction statement	Agree with statement*			Disagree with statement*			Undecided about statement*		
		%A	%D	%U	%A	%D	%U	%A	%D	%U
Science, scientific methodology and terminology										
1	5	57.1	35.7	7.1	15.3	83.0	1.7	0.0	0.0	100.0
2	4	91.1	7.1	1.8	50.0	40.0	10.0	0.0	0.0	0.0
Intentionality of evolution										
6	7	36.8	63.2	0.0	18.5	79.6	1.9	0.0	0.0	100.0
	9	42.1	57.9	0.0	23.6	74.6	1.8	0.0	100.0	0.0
	19	15.8	84.2	0.0	5.5	94.5	0.0	0.0	100.0	0.0
7	8	64.7	23.5	11.8	89.3	10.7	0.0	100.0	0.0	0.0
	10	58.8	23.5	17.7	87.5	10.7	1.8	100.0	0.0	0.0
10	8	88.7	11.3	0.0	60.0	40.0	0.0	50.0	0.0	50.0
Nature of evolution										
11	13	44.0	54.0	2.0	13.0	82.6	4.4	0.0	100.0	0.0
	14	94.0	6.0	0.0	82.6	17.4	0.0	66.7	0.0	33.3
12	14	85.3	11.8	2.9	92.9	7.1	0.0	0.0	0.0	0.0
13	14	92.0	8.0	0.0	89.8	8.2	2.0	50.0	50.0	0.0

Table 4 (continued).

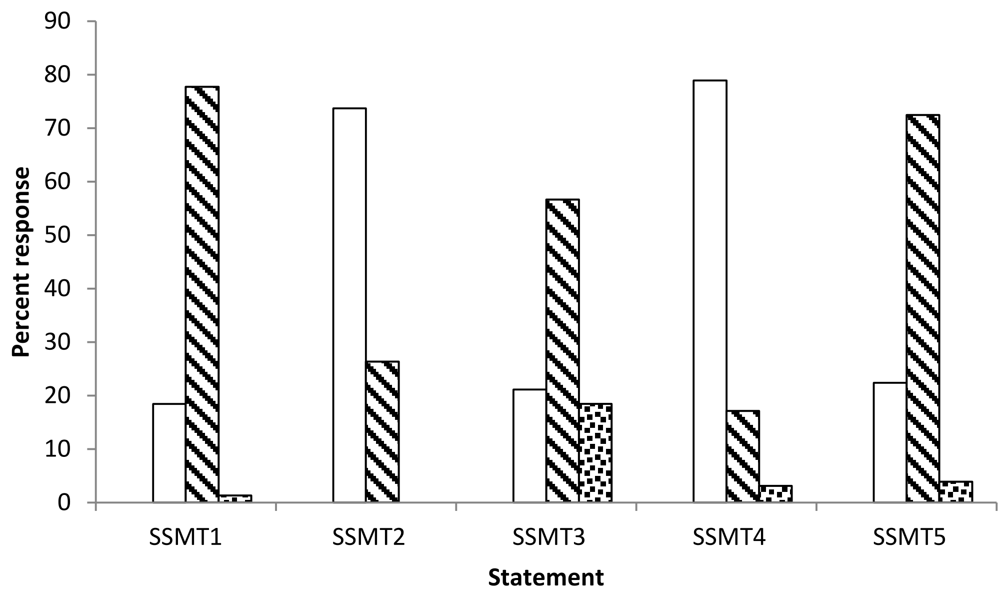
Statement	Interaction statement	Agree with statement*			Disagree with statement*			Undecided about statement*		
		%A	%D	%U	%A	%D	%U	%A	%D	%U
Mechanisms of evolution										
15	9	23.9	76.1	0.0	85.7	14.3	0.0	0.0	50.0	50.0
	16	37.3	62.7	0.0	85.7	14.3	0.0	0.0	100.0	0.0
	17	7.5	92.5	0.0	28.6	71.4	0.0	0.0	50.0	50.0
	18	62.7	32.8	4.5	14.3	71.4	14.3	0.0	50.0	50.0
	19	3.0	97.0	0.0	42.9	57.1	0.0	50.0	50.0	0.0
Evidence supporting evolution										
20	2	89.8	10.2	0.0	45.8	54.2	0.0	33.3	66.7	0.0
	4	98.0	0.0	2.0	45.8	50.0	4.2	33.3	33.3	33.3
	21	14.3	79.6	6.1	41.7	58.3	0.0	0.0	100.0	0.0
	22	14.6	81.2	4.2	41.7	50.0	8.3	66.7	0.0	33.3
	23	79.6	12.2	8.2	75.0	25.0	0.0	33.3	0.0	66.7

Note. Table 4 compares participants' interaction statement responses to those of a specified statement. *A* = agreed; *D* = disagreed; *U* = undecided.

Example: Of those participants who agreed with statement 1, 35.7% disagreed with statement 5.

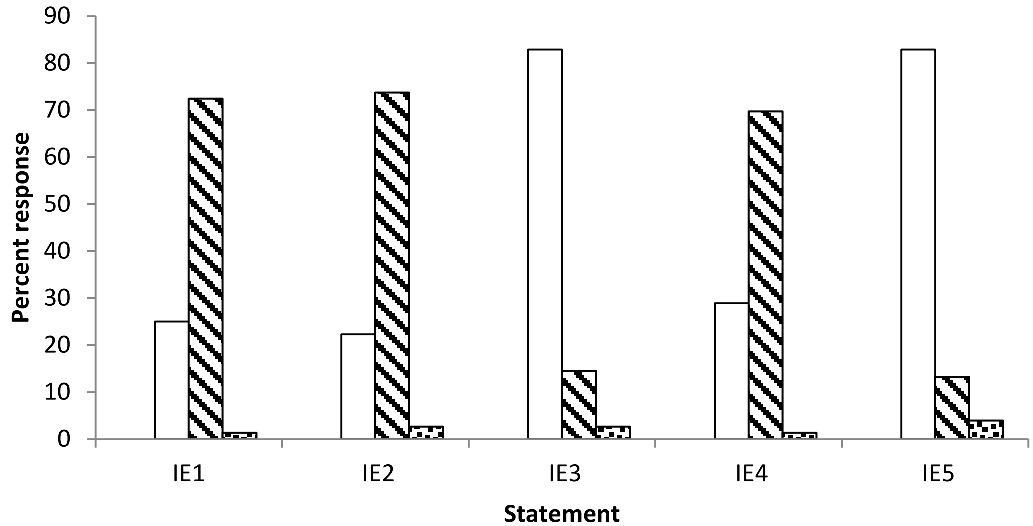
*Response percentages may not total 100 due to rounding.

Figure 1. Percent response to science, scientific method and terminology statements.



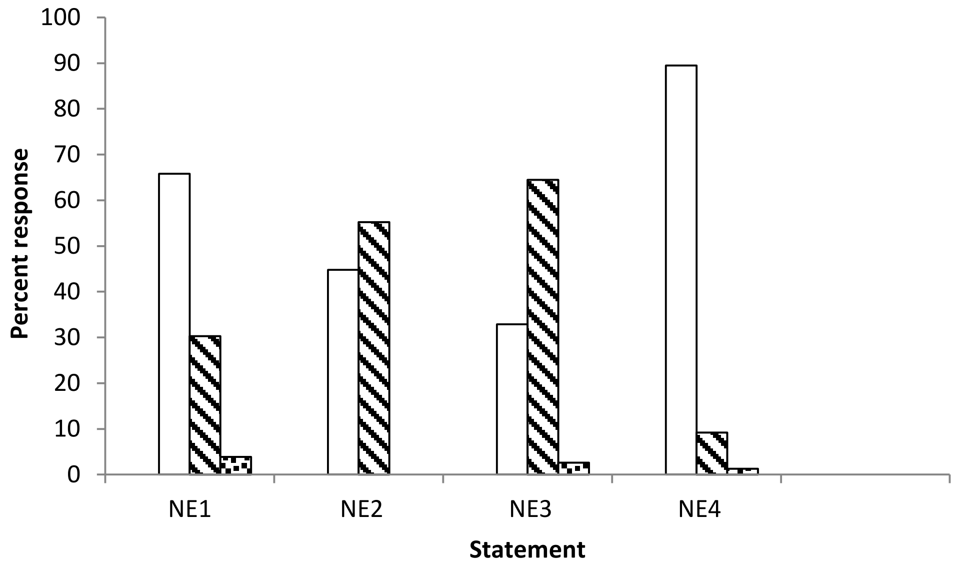
Clear bar = "strongly agree/somewhat agree"; *diagonal bar* = "strongly disagree/somewhat disagree"; *dotted bar* = "undecided/'never heard of it"

Figure 2. Percent response to intentionality of evolution statements.



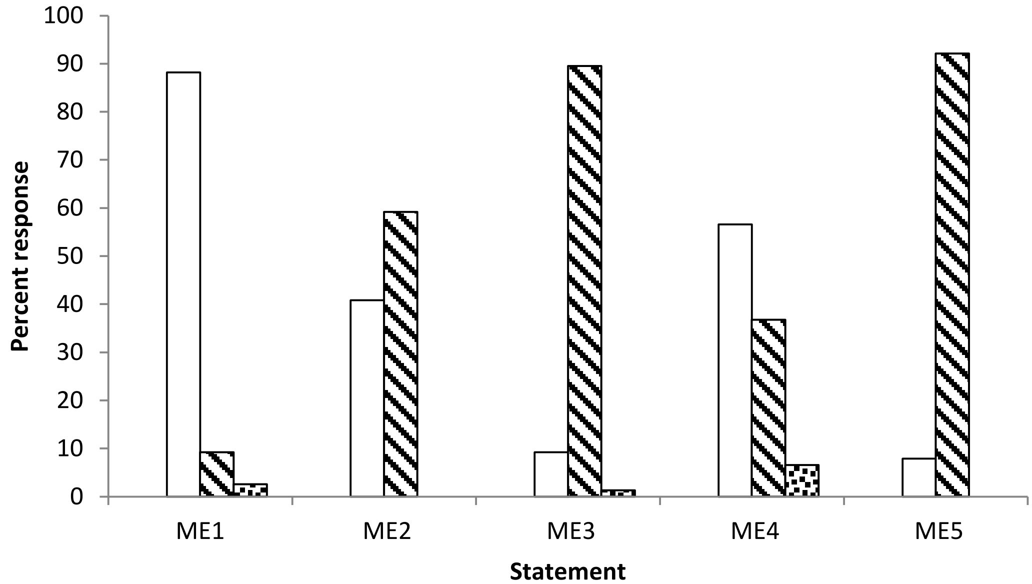
Clear bar = “strongly agree/somewhat agree”; *diagonal bar* = “strongly disagree/somewhat disagree”; *dotted bar* = “undecided/’never heard of it”

Figure 3. Percent response to nature of evolution statements.



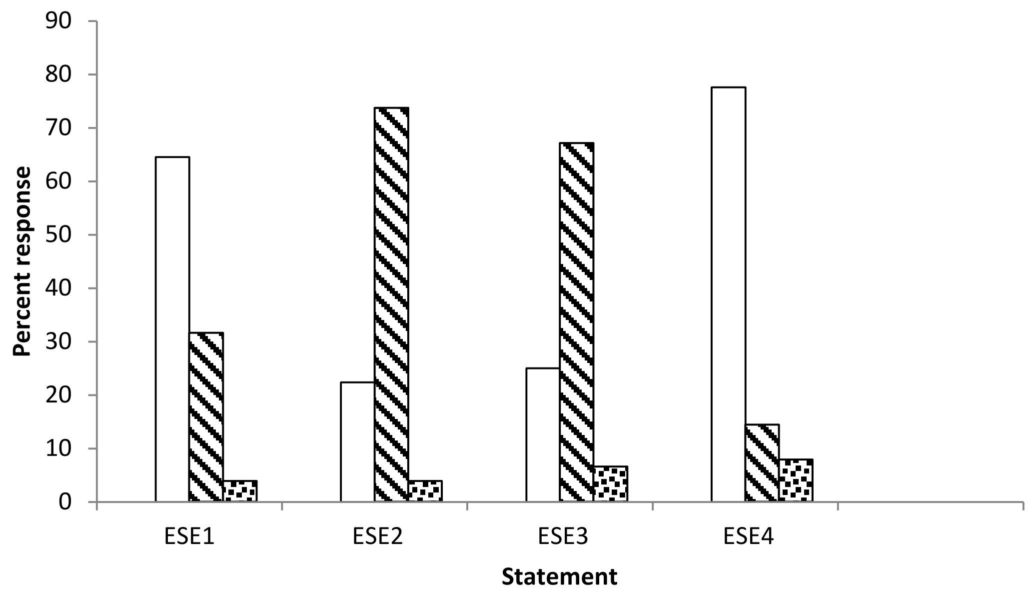
Clear bar = “strongly agree/somewhat agree”; *diagonal bar* = “strongly disagree/somewhat disagree”; *dotted bar* = “undecided/’never heard of it”

Figure 4. Percent response to mechanisms of evolution statements.



Clear bar = "strongly agree/somewhat agree"; *diagonal bar* = "strongly disagree/somewhat disagree"; *dotted bar* = "undecided/'never heard of it"

Figure 5. Percent response to evidence supporting evolution statements.



Clear bar = “strongly agree/somewhat agree”; *diagonal bar* = “strongly disagree/somewhat disagree”; *dotted bar* = “undecided/’never heard of it”

MANUSCRIPT II

A Study Identifying Biological Evolution-related Misconceptions Held by Prebiology Students

This manuscript is prepared for submission to the peer-reviewed journal *Evolution: Education and Outreach* and is the second of three manuscripts prepared for a journal-ready doctoral dissertation.

Abstract

Students bring a diverse array of ideas about natural events to their science classes, and many of these ideas are often at variance with the scientifically accepted views. Numerous studies have identified multiple biological evolution-related misconceptions held by select groups of students. Collectively, these studies repeatedly indicate that students with varying educational backgrounds have difficulties accurately understanding the concepts of evolution. Because scientific literacy in the field of biology necessitates a basic understanding of evolution concepts and theory, students' possession of biological evolution-related misconceptions is problematic. The focus of this study was to identify the types and prevalence of such misconceptions within a state's public high schools' prebiology students and to correlate those findings with demographic variables. Some 993 students enrolled in their initial high school biology course during the 2010 – 2011 academic year in one of 42 Oklahoma public high schools served as this study's unit of analysis. The *Biological Evolution Literacy Survey* (BEL Survey; Yates and Marek 2011), which presents 23 biological misconception statements grouped into five categories, served as the research tool for identifying students' misconceptions, calculating of conception index scores, and collecting demographic data. Analysis revealed participants possess a mean 43.9% rate of understanding of those biological evolution concepts presented in the BEL Survey combined with a 39.1% mean misconception rate. A statistically significant difference in participants' BEL Survey mean index scores (BEL-MIS) when related to biological evolution knowledge self-rating was also disclosed. Strategies for identifying and eliminating students' misconceptions are offered.

Keywords: biology education, evolution education, misconception, Oklahoma, public high school, secondary education, prebiology student

Introduction

Students bring a diverse array of ideas about natural phenomena to their science classes and many of these ideas are often at variance with the scientifically accepted views (Kampourakis and Zogza 2007). Numerous studies conducted in recent decades identify multiple biological evolution-related misconceptions held by select groups of students. These groups include: secondary students (Beardsley 2004; Bizzo 1994; Clough and Wood-Robinson 1985; Creedy 1993; Deadman and Kelly 1978; Demastes et al. 1995; Evans 2000; Geraedts and Boersma 2006; Halldén 1988; Jiménez-Aleixandre 1992; Jungwirth 1975; Kampourakis and Zogza 2007, 2008, 2009; Lawson and Thompson 1988; Palmer 1999; Pedersen and Halldén 1992; Prinou et al. 2008; Settlage 1994; Shtulman 2006; Spindler and Doherty 2009; Tamir and Zohar 1991); first year undergraduate students (Brumby 1979; Jensen and Finley 1995; Nehm and Reilly 2007; Sundberg and Dini 1993); second year undergraduate students (Jiménez-Aleixandre and Fernández-Pérez 1987) collective undergraduate students (Anderson et al. 2002; Bishop and Anderson 1990; Brem et al. 2002; Chinsamy and Plagányi 2007; Demastes et al. 1995; Ferrari and Chi 1998; Hokayem and BouJaoude 2008; Jensen and Finley 1996; Meir et al. 2007; Paz-y-Mińo and Espinosa 2009; Robbins and Roy 2007; Shtulman 2006; Wescott and Cunningham 2005); medical students (Brumby 1984); and physics doctoral students (Chan 1998). Collectively, these studies repeatedly indicate that students of all ages and with varying educational backgrounds have difficulties accurately understanding the concepts constituting evolution (Stern and Ben-Akiva 2007).

More than a century of efforts in evolution education have revealed a diverse array of tenacious and pervasive misconceptions (see Nehm and Schonfeld 2007) ranging from minor misunderstandings to complete theory rejection (Alters and Alters 2001; Dagher and BouJaoude 2005; Evans 2001; Mazur 2004; McComas 2006; Sadler 2005). Repeatedly, studies have shown that students often lack (or reject) a naturalistic scientific worldview (Evans et al. 2010); fail to adopt evolution as a conceptual organizer for the life sciences (Nehm et al. 2009); and utilize faulty evolutionary reasoning patterns (teleology, essentialism, and intentionality) characteristic of young children (Sinatra et al. 2008). These factors contribute to student acquisition and formation of biological evolution-related misconceptions. Common biological evolution misconceptions seem to have a life of their own with some of the most pervasive ones having persisted for decades despite all efforts to correct them (Mead and Scott 2010a; Mead and Scott 2010b; Petto and Mead 2008). The problem of student acquisition and adherence to these misconceptions lies in the fact that scientific literacy in the field of biology necessitates understanding the theory of evolution (Dobzhansky 1973), as emphasized by Bishop and Anderson (1990): "For the science of biology, the theory of evolution provides a unifying framework within which many diverse facts are integrated and explained. For this reason, an understanding of modern biology is incomplete without an understanding of evolution" (p. 415).

To assess public high school prebiology students' knowledge of biological evolution, we surveyed 993 students from across a southern state (U.S. Census Bureau 2010). The specific purpose of this study was to identify the types and prevalence of biological evolution-related misconceptions held by the these students and to correlate these data with known variables including gender, grade level, ethnicity, self-rating of biological evolution knowledge (see Table 1) and students' public high schools' urban-centric and average daily membership (ADM) classifications (see Table 2.) Such a diagnosis of misconceptions is an initial, crucial step in the process of conceptual change (Duit and Treagust 2003). Although we do not claim that the findings of this study undertaken in a single southern state are applicable nationwide, results obtained do contribute to the biological evolution misconception literature and may be compared to similar studies which differ geographically and/or temporally. Additionally, data acquired from this study will be analyzed in a subsequent study in order to identify any changes that may have occurred in the types, prevalence, and correlational relationships of those misconceptions identified as being held by students in this present study following completion of their initial high school biology course.

Method

Participants and Biology Course

Participants included 993 public high school first-year biology students (479 males, 512 females, 2 gender unknown) enrolled during the 2010-2011 academic year in one of 42 of the 474 public high schools located within Oklahoma (Oklahoma State Department of Education [OSDE] 2009a) which served as the study region. For the purposes of this study, a high school is defined as a secondary school offering any combination of grades 9 through 12. All participants were first-time enrollees in a Biology I course at the beginning of the fall 2010 semester. Biology I is a core curriculum course that is required for high school graduation and is typically taken by freshmen and sophomore students (OSDE 2009b). Biology I investigates content, concepts, and principles of major themes in the biological sciences (OSDE 2009c) and serves as the prerequisite course for subsequent high school biology courses students may take (OSDE 2009b).

Instrumentation

To identify student participants' knowledge structure and misconceptions of biological evolution, an instrument was developed called the *Biological Evolution Literacy Survey* (BEL Survey; Yates and Marek 2011, p. 32-33). Initially, student participants' Biology I teachers were contacted via a recruitment letter. Teachers who volunteered for the study ($N = 45$) administered the BEL Survey to students in one section of their Biology I course within the initial week following the beginning of classes in the fall 2010 semester. Teachers were instructed to administer the BEL Survey to students in only one section of the course in order to reduce peer influence on students' opinions concerning the survey statements. Administering the survey as early as possible in the course was done to minimize students' exposure to biological evolution concepts taught in their initial high school biology course and to reduce teacher influence on students' opinions concerning the BEL Survey statements.

With permission, the BEL Survey was modeled after Cunningham and Wescott's 2009 survey which, in turn, was adapted from Almquist and Cronin (1988) with additions from Wilson (2001), and Bishop and Anderson (1986, 1990). The initial survey produced by Almquist and Cronin attempted to identify college and university students' basic knowledge concerning the processes of evolution and their opinions on issues pertaining to science and religion. The purpose of Cunningham and Wescott's 2009 study was to identify the common misconceptions held by undergraduate students and to explain the reasoning behind those misconceptions. In addition, Cunningham and Wescott were interested in assessing how students' opinions and understanding of evolutionary theory may have changed in the interim since the 1988 Almquist and Cronin study.

The BEL Survey is composed of two sections to be completed in anonymity. The first section requested demographic data which included gender, grade level, ethnicity, self-rating of evolution knowledge, and indication as to whether the student had previously enrolled in a Biology I course. Any student whose survey indicated previous enrollment in a Biology I course was omitted from the study. The second section of the BEL Survey asked student participants to respond to whether they strongly agree, somewhat agree, strongly disagree, somewhat disagree, or have no opinion ("undecided/or never heard of it") on 23 statements related to biological evolution-related misconceptions. Two methods of scoring responses were used during data analysis. First, the responses "strongly agree" and "somewhat agree" were combined, indicating participant agreement with the statement. Likewise, the responses "strongly disagree" and "somewhat disagree" were combined, indicating participant disagreement with the statement. Second, by means of Likert scaling of responses, a biological evolution misconception scoring index was created with answers to statements indicative of a low acceptance of an evolution concept (high acceptance of the associated misconception) receiving low scores and answers to statements indicative of a high acceptance of an evolution concept (nonacceptance of misconception) receiving high scores. For statements in which agreement indicated nonacceptance of the associated misconception (statements 2, 4, 8, 10, 11, 14, 15, 18, 20, 23), index scoring was as follows: (a) strongly agree, score of 5; (b) somewhat agree, 4; (c) undecided/ never heard of it, 3; (d) somewhat disagree, 2; (e) strongly disagree, 1; and (f) no response, 0. For statements in which agreement indicated a high acceptance of the associated misconception (statements 1, 3, 5, 6, 7, 9, 12, 13, 16, 17, 19, 21, 22) index scoring was as follows: (a) strongly agree, 1; (b) somewhat agree, 2; (c) undecided/never heard of it, 3; (d) somewhat disagree, 4; (e) strongly disagree, 5; and (f) no response, 0. The possible range of BEL Survey index scores was 0 to 115 with a score of 115 representing the highest level of understanding coupled with a lack of associated misconceptions whereas lower indices represented lower levels of understanding combined with higher levels of biological evolution-related misconceptions. In addition, a count of the number of misconceptions revealed by responses to the statements was conducted.

Cunningham and Wescott's (2009) survey instrument on which the BEL Survey is modeled contained 24 statements classified into four categories: (a) evolutionary theory, (b) scientific facts, (c) process of evolution, and (d) language of science. For the present study, Cunningham and Wescott's four-category classification was modified into five categories of biological evolution-related misconceptions that are commonly employed in the literature (e.g., Alters and Alters 2001; Bishop and Anderson 1990; Greene 1990; Gregory 2009; Jensen and Finley 1996; Wandersee et al. 1994; Wescott and Cunningham 2005; Wilson 2001). These misconception categories include: (a) science, scientific methodology and terminology (SSMT); (b) intentionality of evolution (IE); (c) nature of evolution (NE); (d) mechanisms of evolution (ME); and (e) evidence supporting evolution (ESE). While five biological evolution-related misconception statements were identified or developed for each of the SSMT, IE, and ME categories, four such statements were identified or developed for each of the NE and ESE categories. Of the BEL Survey's 23 statements (see Table 3), two statements (11 and 16) were taken directly from Cunningham and Wescott's survey; eight were adapted from Cunningham and Wescott's survey (1, 6, 7, 9, 15, 17, 20, 22); and, the remaining 13 statements (2, 3, 4, 5, 8, 10, 12, 13, 14, 18, 19, 21, 23) were developed through an extensive search of biological evolution misconception literature.

Results and Discussion

Table 1 presents the participant profile. Approximately 52% percent of study participants were female (*n* = 512) and 48% male (*n* = 479). The majority of students were sophomores (72.1%, *n* = 716) with only a combined 3.5% (*n* = 35) being either juniors or seniors. Although 71.8% (*n* = 713) of participants were white, non-Hispanic, Oklahoma's rich ethnic diversity was revealed with 15.8% (*n* = 157) of participants claiming American Indian or Alaska Native descent, while 5.6% (*n* = 56) were Hispanic. When asked to rate their knowledge of biological evolution prior to instruction in the Biology I course, 80.6% (*n* = 800) indicated an average or less than average knowledge whereas a combined 18.3% (*n* = 182) claimed either a good or excellent knowledge of biological evolutionary concepts. Student participants were fairly evenly split between public high schools possessing an ADM greater than 242.3 (52.1%, *n* = 517) and those high schools with an ADM equal to or less than 242.3 (48.0%, *n* = 476). In terms of urban-centric classification, rural designated high schools housed the majority of participants (49.5%, *n* = 492) while city designated schools held the minority (2.5%, *n* = 25). Cronbach's alpha of 0.848 was identified for the

23-statement BEL Survey which indicates that the internal reliability of the survey is acceptable. Additionally, if any one statement is deleted, the reliability coefficient does not decrease by more than 0.014, thus maintaining the survey's internal reliability.

Significant Differences

Chi-square statistics were used to identify significant differences ($p < .05$) among variables related to the 42 public high school containing the study's 993 student participants and the sum total 474 public high schools located within the study area (see Table 2). A comparison between the two sets of schools focused on two variables: (a) distribution of student ADM (Institute of Education Sciences National Center for Educational Statistics [IESNCES] 2010a), and (b) urban-centric classification (IESNCES 2010b). A chi-square goodness-of-fit statistical analysis revealed no significant difference ($p < .05$) between the two high school groups for ADM distribution, χ^2 (4, $N = 42$) = 4.29, $p = .37$. This result indicates that the 42 public high schools from which the student participants originated were representative of the collective 474 public high schools within the study region for ADM. A chi-square goodness-of-fit statistical analysis did reveal a significant difference ($p < .05$) between the two public high school groups when urban-centric classification was compared, χ^2(3, N = 42) = 8.0, $p = .046$. This result indicates that the 42 public high schools from which the student participants originated were not representative of the collective 474 public high schools within the study area in terms of urban-centric classification. A 14.45 confidence interval at a 95% confidence level was identified for the sample of high schools ($n = 42$) representing the study's 993 student participants compared to the number of public high schools located within the study region ($N = 474$).

No significant difference was identified between the ratio of males (48.3%) to females (51.7%) in the study population (n = 991) when compared to the ratio of males (51.5%) to females (48.5%) within the study region (N = 176,679; IESNCES 2010c) χ^2 (1, N = 991) = 0.41, p = .52. However, a significant difference was identified between the ratios of students' ethnicities in the participant population when compared to those of all public high school students within the study region (see Table 1; IESNCES 2010c), χ^2 (4, N = 997) = 12.2, p = .02. These results indicate that the gender ratio of student participants was representative of the gender ratio for all students within the study region whereas participants' ethnicity ratios were not. The difference between participants' actual and expected ethnicity ratios may, in part, be attributed to a difference in ethnicity ratios between urban and rural settings in Oklahoma (U.S. Census Bureau 2009). Rural settings in Oklahoma possess greater percentages of White non-Hispanics (+ 9.3%) and American Indians (+3.3%) and lesser percentages of Hispanics (-6.0%), Asians (-1.3%), and Black non-Hispanics (-7.2%) as opposed to urban settings (U.S. Census Bureau 2009). This study possesses a higher than expected percentage of participants' public high schools designated in town and rural locations (+3.4%) and a lower than expected percentage of participants' schools designated in suburban and city locations (-3.4%). This discrepancy may have resulted in higher percentages of White non-Hispanic and American Indian participants and lower percentages of Hispanic, Asian, and Black non-Hispanic participants than expected.

Out of a possible maximum BEL Survey index score of 115, student participants in this study (N = 993) earned a 70.34 (SD = 7.04) mean index score. Table 1 identifies participants' BEL-MIS compared to specific variables. Although previous studies have shown that student misconceptions concerning science can differ significantly based on multiple variables including geographical region, religious background, generation, gender, and age (Almquist and Cronin 1988; Losh et al. 2003; Morrison and Lederman 2003; Palmer 1999), this study found no significant differences ($p < .05$) between students' BEL-MIS when related to students' gender, grade, ethnicity, or public high schools' urban-centric location or ADM. However, a significant difference was revealed between students' BEL-MIS when compared to two sets of biological evolution knowledge self-rating descriptors: *good* ($M = 72.55$, $SD = 8.46$, $n = 146$) versus *poor* ($M = 68.92$, $SD = 6.53$, $n =143$) and *good* versus *fair* ($M = 69.49$, $SD = 6.50$, $n = 224$). This result seems to indicate a direct correlation between students' self-rating of biological evolution knowledge and their actual knowledge as students' BEL-MIS increased sequentially with the ratings *poor* ($M = 68.92$), fair ($M = 69.49$), *average* ($M = 70.56$), and *good* ($M = 72.55$). However, readers should proceed with caution as those students who selected the *excellent* descriptor for their biological evolution knowledge produced a BEL-MIS of just 70.08, lower than both the good and average descriptor categories. This result may in part be due to the small sample size of students who selected the excellent descriptor ($n = 36$) as opposed to the sample sizes of students who selected the other four descriptors ($n = 143$ to 433).

Science, Scientific Methodology and Terminology

Table 3 lists each BEL Survey statement and accompanying participant percent response. The combined percent responses of participants highlighted in gray identifies the percentage of participants who held the accompanying statement's associated misconception whereas the combined pair of percent responses in the adjacent nonhighlighted regions (either 1 and 2 or 3 and 4) identifies the percentage of participants who held the correct concept as related to the statement. Table 4 identifies interactions between participants' responses to selected statements. Statements 1 through 5 address the general opinions of student participants concerning science, scientific methodology and terminology as they relate to evolutionary theory. Figure 1 illustrates the responses to each of these statements.

The word *theory* is perhaps the most misunderstood word in science (Scott 2004). In everyday usage, *guess* or *hunch*--terms that imply speculation or conjecture--are synonyms for theory. Yet according to the National Academy of Sciences (NAS), a scientific theory is defined as "a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses" (1998, p. 7). Students who possess misconceptions of scientific theory typically understand theory in the speculative sense (Alters and Alters 2001; Dagher and BouJaoude 1997; Smith and Sullivan 2007) as in *evolution is only a theory*. Responses to statement 1 ("A scientific theory that explains a natural phenomenon can be defined as a 'best guess' or 'hunch'") reveal only 34.0% (n = 338) of students correctly interpreted the term *theory* as used in a scientific context whereas 50.0% (n = 496) failed to differentiate between the scientific concept of *theory* and its usage in common vernacular. Statement 5 ("Evolution cannot be considered a reliable explanation because evolution is only a theory") fared little better with 34.2% (n = 340) correctly relating the accurate definition of a scientific *theory* to the *theory of evolution* while 54.8% (n = 544) were unable to do so. Analysis found 40.2% (n = 136) of participants who disagreed with statement 1 (n = 338) also in disagreement with statement 5, indicating that only 13.8% of participants (*n* = 136) who completed both statements 1 and 5 (*n* = 987) understand the term *theory* in the scientific context and correctly apply that meaning to the *theory of evolution*. Of those participants who appear to possess an accurate conception of a scientific *theory* as indicated by their negative response to statement 1 (*n* = 338), 50.3% (*n* = 170) contend that evolution cannot be considered a reliable explanation because evolution is *only a theory*. And, of those participants in agreement with statement 1 (*n* = 496), 57.7% (*n* = 286) were consistent in their misconception by also agreeing with statement 5. This outcome indicates that for these participants—representing 28.8% (*n* = 286) of all participants--the scientific use of *theory* does not differ from that of common usage (as in "best guess" or "hunch") and therefore evolution cannot be deemed reliable because it is *only a theory*. Students possessing such a concept of theory no doubt consider evolution to be a weak science.

A basic premise in evolutionary theory is the large expanse of time required for evolutionary processes to occur. Students are known to hold misconceptions related to the evolutionary time scale with many believing that evolution occurs over centuries rather than tens and hundreds of millennia (Robbins and Roy 2007). Dating techniques provide evidence of the timeline of evolution. Alters and Alters (2001) lamented the number of students who have come to believe that dating techniques are questionable while Scott (2004) detailed 20 such misconceptions. Based on these misconceptions, students tend to view calculated dates as inaccurate. However, this study revealed a relatively high percentage of participants (73.3%, *n* = 727) who agreed with statement 2 ("The scientific methods used to determine the age of fossils and the earth are reliable") while 21.2% (*n* = 210) held to the misconception. A comparative statement, statement 4

("The Earth is old enough for evolution to have occurred"), received a less favorable response with only 56.8% (*n* = 564) in agreement while 31.7% (*n* = 315) disagreed. With 62.3% (*n* = 453) of participants who agreed with statement 2 (*n* = 727) also agreeing with statement 4, a very small positive correlation was revealed between participants' understanding of the reliability of dating techniques (statement 2) and the age of the Earth (statement 4), $r(984) = .06$, $p > .05$). Such a small correlation, however, indicates much diversity in student responses as evidenced by 29.0% (*n* = 288) of participants who presented conflicting opinions of statements 2 and 4, with 8.9% (*n* = 88) disagreeing with statement 2 while agreeing with statement 4. While these individuals adhere to the misconception that scientific dating methods are not reliable, they do understand that the Earth is old enough for evolution to have occurred. Conversely, 20.1% (*n* = 200) agreed with statement 2 while at the same time disagreed with statement 4. Although these participants understand that scientific dating techniques are reliable they possess the conflicting opinion that the Earth is not old enough for evolution to have occurred.

The second law of thermodynamics explains that in a closed system energy tends to travel from organized to disorganized states in the form of heat (Futuyma 1995). If students fail to understand that life operates within an open system with a constant inflow of energy, a commonly held misconception develops which describes evolution in violation of the second law of thermodynamics. Such a misconception precludes complex organisms evolving from simpler ones (Alters and Alters 2001; Berra 1990; Futuyma 1995; Scott 2004; Smith and Sullivan 2007) as was evident in 21.4% (*n* = 212) of participants who agreed with statement 3 ("According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms”). A combined 42.8% of students (*n* = 425) either claimed *undecided/never heard of it* or failed to state an opinion. Statement 3 generated the greatest percentage of *undecided/never heard of it* responses of all the BEL Survey’s 23 statements with a 41.9% (*n* = 416) response rate.

Participants possessed a 46.8% mean rate of understanding coupled with a 35.8% mean misconception rate in response to the five *Science, Scientific Methodology and Terminology* survey statements while 17.4% (*n* = 173) of participants per statement were undecided or did not respond. Expressing no misconceptions related to the five statements were 13.6% (*n* = 135) of participants (*N* = 993) while 29.6% (*n* = 294) held one misconception; 30.1% (*n* = 299), two misconceptions; 19.3% (*n* = 192), three misconceptions; 5.9% (*n* = 59), four misconceptions; and 1.4% (*n* = 14) held misconceptions related to each of the five statements. Collectively, 86.4% (*n* = 858) of participants held one or more misconceptions related to the *Science, Scientific Methodology and Terminology* category statements.

Intentionality of Evolution

The five statements of the BEL Survey *Intentionality of Evolution* section were designed to measure participants’ misconceptions of biological evolution intentionality. Misconceptions associated with evolution intentionality subscribe a type of conscious will and directive to the mechanisms of evolution. Figure 2 illustrates the responses to each of these statements. Responses from statement 6 (“Evolution always results in improvement”) reveal that 54.1% (*n* = 537) of participants disagreed with the statement and therefore understand that the process of evolution does not always result in improvement, while 30.0% (*n* = 298) agreed with statement 6, indicating an adherence to the misconception that evolution always does result in improvement. Statement 7 ("Members of a species evolve because of an inner need to evolve") found 40.1% (*n* = 398) in disagreement while 38.4% (*n* = 381) agreed, indicating that a slight majority of participants understand that evolution is not based on need. A small positive correlation, $r(972) = .23$, $p < .01$) exists between results for statements 6 and 7 with 46.2% (*n* = 248) of participants who disagreed with statement 6 (*n* = 537) also in disagreement with statement 7. Of those participants who held the misconception identified in statement 6, 48.7% (*n* = 145) also shared the misconception described in statement 7. This result indicates a tendency among these students to view evolutionary processes as deterministic in nature with improvement as their goal.

Participant agreement with statement 9 ("If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation") also implies a deterministic view of evolutionary mechanisms. The majority of students, 40.3% (*n* = 400), did reveal such a misconception by agreeing with statement 9, while 34.4% (*n* = 341) were in disagreement. A small positive correlation, $r(968) = .167$, $p < .01$ was disclosed between participants' responses to statements 6 and 9 with 19.9% (*n* = 193) of participants who responded to both statements (*n* = 968) possessing neither misconception. However, 14.4% (*n* = 139) of participants claimed both the misconceptions associated with statements 6 and 9. Of those participants who disagreed with statement 6 (*n* = 537), 40.4% (*n* = 217) agreed with statement 9, and of those participants who disagreed with statement 9 (*n* = 341), 28.7% (*n* = 98) agreed with statement 6. These results reveal that

32.5% (*n* = 315) of participants who answered both statements 6 and 9 (*n* = 968) possessed contradictory conceptions in regard to intentionality of evolution as related to these statements.

Statement 10 (“Evolution cannot cause an organism’s traits to change within its lifetime”) produced 37.1% (*n* = 368) agreement among participants, with 43.2% (*n* = 429) in disagreement, signifying that the majority of participants adhere to the misconception that evolutionary processes can produce change in individual organisms during their lifetimes. Among those participants in agreement with statement 10, 42.4% (*n* = 156) also disagreed with statement 7 suggesting that only 16.0% (*n* = 156) of those participants who addressed both statements 10 and 7 (*n* = 978) correctly understand that evolution is not driven by need and cannot cause an organism’s traits to change within its lifetime. However, 44.0% (*n* = 175) of those participants who disagreed with statement 7 (*n* = 398) also disagreed with statement 10. While these participants understand that evolution is not driven by need, they hold the misconception that evolution can act upon an organism’s traits during its lifetime. Holding misconceptions related to both statements 7 and 10 were 18.7% (*n* =183) of participants, disclosing the mistaken idea that members of a species evolve because of an inner need to evolve and these needs can be fulfilled via the process of evolution during the lifetime of the organism. A small positive correlation exists between statements 7 and 10, $r(978) = .104$, $p < .01$, indicative of the fact that 50.6% (*n* = 502) of participants (*N* = 993) possessed at least one misconception related to statements 7 and 10.

Statement 8 (“Traits acquired during the lifetime of an organism--such as large muscles produced by body building--will not be passed along to offspring”) found agreement among 55.9% ($n = 555$) of participants as opposed to 35.7% ($n = 354$) who held to the Lamarckian misconception of inheritance via acquired characteristics. A small positive correlation of $r(979) = .124$, $p < .01$ was discovered between participant responses to statements 8 and 10 ("Evolution cannot cause an organism's traits to change within its lifetime"). Of those participants in agreement with statement 10 ($n = 368$), 59.8% ($n = 230$) also agreed with statement 8. These results indicate that only 23.2% ($n = 230$) of participants correctly understand that characteristics acquired by an organism during its lifetime are not produced by evolutionary processes nor can acquired traits be passed along to the next generation. Of those participants disagreeing with statement 10 ($n = 429$), 38.9% ($n = 167$) disagreed with statement 8. These 167 individuals, representing 16.8% of the participant population, not only adhere to the misconception that traits acquired during the lifetime of an organism can be passed on to offspring but that such traits can be produced via evolutionary processes as well. Similarly, 38.1% ($n = 145$) of the 381 participants who agreed with statement 7 also disagreed with statement 8. These individuals, representing 14.6% of student participants, adhere to the two related misconceptions that evolution occurs as a response to need and traits acquired during the lifetime of an organism can be inherited by offspring.

This tendency of secondary school students toward biological evolution explanations based on purpose is common and persistent throughout the literature (e.g., Alters and Nelson 2002; Beardsley 2004; Bizzo 1994; Clough and Wood-Robinson 1985; Deadman and Kelly 1978; Geraedts and Boersma 2006; Jensen and Finley 1996; Jiménez-Aleixandre 1992; Kampourakis and Zogza 2008, 2009; Passmore and Stewart

2002; Pedersen and Halldén 1992; Prinou et al. 2008; Samarapungavan and Wiers 1997; Settlage 1994; Shtulman 2006; Southerland et al. 2001; Tamir and Zohar 1991) and even into postsecondary education (Kelemen and Rosset 2009). In fact, in a study of university nonmajor biology students, Jensen and Finley (1996) identified the most common misconception responses were related to purposeful evolution.

Collectively, participants own a 44.3% mean rate of understanding coupled with a 37.5% mean misconception rate in response to the five *Intentionality of Evolution* survey statements while 18.2% of participants per statement were undecided or did not respond. Expressing no misconceptions related to the five statements were 12.8% (n = 127) of participants while 28.1% (n = 279) held one misconception; 28.9% (n = 287), two misconceptions; 21.0% (n = 208), three misconceptions; 7.5% (n = 75), four misconceptions; and 1.7% (n = 17) held misconceptions related to each of the five statements. Collectively, 87.2% (n = 866) of participants held one or more misconceptions related to the *Intentionality of Evolution* statements.

Nature of Evolution

Participants' conceptions related to the nature of evolution, including the roles of randomness, the environment in evolutionary processes, and adaptation, were addressed in the *Nature of Evolution* statements, 11-14. Figure 3 illustrates the responses to each of these statements. Responses from statement 11 ("New traits within a population appear at random") were evenly split with 41.2% (n = 409) of participants in agreement whereas 41.6% (n = 413) adhered to the misconception. Statement 13 ("Evolution is a totally random process") resulted in 25.9% (n = 257) of participants agreeing with the misconception while 51.5% (n = 511) disagreed. A medium positive correlation of $r(984) = .27$, $p < .01$ between statements 11 (positive) and 13 (negative) reveals much diversity of opinion among participants as 59.5% ($n = 591$) possessed at least one misconception for the combined statements. Of those students in agreement with statement 11 ($n = 409$) who correctly identified that new traits appear in the population at random, 35.9% ($n = 147$) claimed that evolution is a totally random process, adhering to the misconception identified in statement 13. Conversely, of those participants who disagreed with statement 11 ($n = 413$), 19.1% ($n = 79$) also agreed with statement 13, presenting the conflicting misconceptions that evolution is a totally random process, yet new traits within a population do not appear at random. These elevated levels of misconception among participants concerning the concept of randomness are a bit disconcerting as Isaak (2003) contends there is no other misconception which is a better indication of lack of understanding of evolution than the misconception that evolution proceeds by random chance. Although randomness does play a role in pivotal evolutionary mechanisms such as the origination of variations, with the environment selecting specific variations within populations, evolution in totality is a nonrandom process (Smith and Sullivan 2007).

Statement 14 ("The environment determines which traits are best suited for survival") found a majority of participants correctly agreeing (59.8%, $n = 594$) while 27.5% ($n = 273$) disagreed. Of those participants agreeing with statement 11 ($n = 409$; "New traits within a population appear at random"), 62.1% ($n = 254$) also agreed with statement 14 revealing that 25.6% ($n = 254$) of participants correctly understand these two major premises of natural selection. Holding to one misconception associated with statements 11 and 14, however, were 56.7% ($n = 563$) of participants while 12.4%

(*n* = 123) revealed misconceptions associated with both statements. Possessing accurate concepts for both statements 13 and 14 were 34.1% of participants (*n* = 339). Of those participants agreeing with statement 13 (*n* = 257), 58.8% (*n* = 151) also agreed with statement 14. While these students understand that the environment plays a key role in determining which traits are best suited for survival, they hold the contradictory view that evolution is a totally random process. Conversely, of those individuals who correctly disagreed with statement 13 (*n* = 511), 26.4% (*n* = 135) also disagreed with statement 14. For these participants, evolution is not a totally random process, yet the environment fails to play a role in trait survivability.

Statement 12 ("Individual organisms adapt to their environments") found 13.4% (*n* = 133) of participants in disagreement whereas a large 80.1% (*n* = 796) were in agreement, claiming the associated misconception. The relatively high percentage of participants possessing this misconception as compared to the average misconception rate (39.1%) raised concern. During the BEL Survey design, it was apparent that respondents might interpret the term *adapt* in a nonevolutionary context such as "to adjust (oneself) to a new or changing circumstances" (Guralnick 1980, p. 15), as in a herd of elk moving to lower elevations in the summer to forage, as opposed to the intended evolutionary usage of the term whereas populations of organisms--not individuals--adapt to their environment via evolutionary mechanisms such as natural selection. In order to reduce the probability of this occurrence, in the BEL Survey participants' instructions section emphasis was placed on informing participants that ". . . your opinions concerning *biological evolution* concepts will be identified." Whether all participants adhered to this admonition (or understood) is, of course, unknown, so there may be participants who were recognized as adhering to the misconception revealed by statement 12 when in reality they may have failed to address the term *adap*t in an evolutionary context. Since these students entered the study with little academic exposure to biological evolution concepts, it is reasonable to assume that such may be the case.

Of those in disagreement with statement 12 (n = 133), 48.9% (n = 65) were in agreement with statement 14 ("The environment determines which traits are best suited for survival"). While these individuals correctly attributed the role of adaptation to the environment rather than to the individual organism, they represent only 6.7% of the total number who responded to both statements 12 and 14 (n = 975). Of those individuals disagreeing with statement 12 (n = 133) 39.8% (n = 53) also disagreed with statement 14. For these participants, individual organisms do not adapt to their environments yet the environment fails to play a role in determining the survivability of traits and hence the development of adaptations. Of those participants agreeing with statement 12 (n = 796), 64.6% (n = 514) also agreed with statement 14. This group of students confers the ability to adapt to the environment to individual organisms with the environment, in turn, determining which traits are best suited for survival. Not surprisingly, with the large number of misconceptions evident in participants concerning statements 12 (negative) and 14 (positive) a medium positive correlation resulted, $r(975) = .28, p < .01$.

Participants averaged a 41.5% mean rate of understanding, a 43.8% mean misconception rate, and 14.7% mean undecided or nonresponse rate to the four *Nature of Evolution* survey statements. Expressing no misconceptions related to the four statements were 5.9% (*n* = 59) of participants while 32.1% (*n* = 319) held one misconception; 44.6% (*n* = 443), two misconceptions; 15.5% (*n* = 154), three misconceptions; and 1.8% (n = 18) held misconceptions related to each of the four statements. Collectively, 94.1% of participants (*n* = 934) held one or more misconceptions related to the four *Nature of Evolution* statements.

Mechanisms of Evolution

Statements 15 through 19 address the opinions of student participants concerning mechanisms that lead to evolutionary change. Figure 4 illustrates the responses to each of these statements. One of the primary mechanisms for evolutionary change is natural selection which determines which members of a population will survive long enough to reproduce and transmit their genes to the next generation. The theory of natural selection calls for variations within a population. Those population members possessing variations that give them an advantage in the environment in which they reside are thus granted a reproductive advantage over those members with less advantageous variations. The majority of students (40.1%; *n* = 398) agreed with statement 15 ("Variation among individuals within a species is important for evolution to occur") whereas 28.7% (*n* = 285) held the misconception that variation among members of a species is not important to evolutionary processes. These finding concur with the literature which indicates that students may not view genetic variation as important to evolution, even though such variation is essential to evolution taking place (Alters and Nelson 2002; Bishop and Anderson 1990; Gregory 2009; Mayr 1982; Rutledge and Warden 2002) or that variations only affect outward appearance, and do not influence survival (Anderson et al. 2002).

The literature is replete with student misconceptions about both nonadaptive and adaptive traits and their respective roles in evolution. Students may incorrectly assume that traits are always beneficial and only these traits are passed along to offspring (Gregory 2009). The majority of student participants were not of such opinion with 59.2% (n = 588) disagreeing with statement 19 ("Only beneficial traits are passed on from parent to offspring.") while the minority, 30.6% (n = 303), adhered to the misconception crediting hereditary mechanisms in transmitting only beneficial traits from generation to generation. Of those participants agreeing with statement 15 (n = 398), 60.3% (n = 240) disagreed with statement 19, yet 10.2% (n = 101) of participants voiced opposite opinions by disagreeing with statement 15 while simultaneously agreeing with statement 19. This later result appears to indicate that while these participants believe variation among individuals within a species is not important for evolution to occur, they contend that only beneficial traits are passed from parent to offspring. A small positive correlation between the two statements, $r(980) = .13$, $p < .01$, was the result of 38.8% (n = 385) of participants possessing at least one misconception between statements 15 (positively oriented) and statement 19 (negatively oriented). Of those participants agreeing with statement 15 (n = 398), 50.5% (n = 201) also agreed with statement 9 ("If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation"). While understanding the importance of variation in evolutionary change, these individuals fail to completely understand those mechanisms which contribute to variation within a population.

Of those participants disagreeing with statement 6 (“Evolution always results in improvement”), 67.6% (n = 363) also disagreed with statement 19, producing a small positive correlation, $r(968) = .175$, $p < .01$. These students, representing 37.5% of respondents to both statements (n = 968), correctly understand that evolution does not always result in improvement as inheritance does not dispense only beneficial traits, but harmful traits as well. Of those individuals agreeing with statement 6 (n = 298), 49.0% (n = 146) disagreed with statement 19. While these individuals inaccurately view evolution as a process which always results in improvement, they correctly disagree that only beneficial traits are passed from generation to generation. Agreeing with both statements 6 and 19 were 127 participants, representing 13.1% of responding participants (n = 968). For these participants, only beneficial traits are passed from parent to offspring, necessitating that evolution always result in improvement.

Many student-held misconceptions about natural selection involve misinterpretation of the phrase *survival of the fittest*, the most commonly used phrase drafted into everyday speech from the theory of evolution (Smith and Sullivan 2007). Darwin (1872) defined survival of the fittest as: “[The] preservation of favourable individual differences and variations, and the destruction of those which are injurious” (p. 63). Research has found that students commonly identify the meaning of survival of the fittest as directly related to physical strength, speed, intelligence or longevity (Anderson et al. 2002; Bishop and Anderson 1990; Robbins and Roy 2007), the number of mates possessed, or even the physical fighting among different species with the strongest species winning (Anderson et al. 2002). *Survival of the fittest* misconceptions were pervasive in student participants as 62.5% (n = 621) agreed with statement 16

("'Survival of the fittest' means basically that 'only the strong survive'"). For those individuals agreeing with statement 15 ("Variation among individuals within a species is important for evolution to occur"; *n* = 398), 33.2% (*n* = 132) also disagreed with statement 16 while for those participants disagreeing with statement 15 (*n* = 285), 62.1% (*n* = 177) also agreed with statement 16. This pair of misconceptions, evident in 17.8% (*n* = 177) of participants (*N* = 993), is indicative of faulty understanding of both the role of variation in evolution and its relationship to fitness.

Statement 17 ("The size of the population has no effect on the evolution of a species") resulted in disagreement among 54.9% (*n* = 545) of participants while 30.1% (*n* = 299) revealed their misconception by affirming the statement. Of those participants in agreement with statement 15 (*n* = 398), 60.3% (*n* = 240) also disagreed with statement 17. While these students appear to understand that both variation among individuals within a species and population size are factors which contribute to evolution, the correlation does not reveal whether they correctly understand the relationship between population size and variation within a population. There is little doubt that 31.9% (*n* = 127) of those participants in agreement with statement 15 (*n* = 398) fail to understand the relationship between population size and variation within a population as they were also in agreement with statement 17. While these individuals may understand the role of variation in evolutionary processes, they fail to understand the contribution of population size. Likewise, a failure to grasp the relationship between variation and population size as they relate to evolution can be said of those participants who disagreed with statement 15 (*n* = 285) and either agreed (*n* = 83) or disagreed (*n* = 178) with statement 17. As only 24.2% (*n* = 240) of participants lacked misconceptions related to both statements 15 (positive orientation) and 17 (negative orientation), a small positive correlation was produced between the responses to both statements, $r(988) = .133, p < .01$.

Students may believe that complex structures such as eyes or wings could not have been formed by evolutionary processes since intermediate steps would seem to be inviable or nonfunctional (Nelson 2008). In this study, only 36.6% ($n = 363$) agreed with statement 18 (“Complex structures such as the eye could have been formed by evolution”) whereas 45.0% ($n = 440$) held to the misconception and 17.9% ($n = 178$) were undecided. A medium positive correlation of $r(984) = .319, p < .01$ was identified between the responses to statements 15 (positive oriented) and 18 (positive oriented). Of those participants in agreement with statement 15 ($n = 398$), 47.5% ($n = 189$) also agreed with statement 18 revealing that 19.0% ($n = 189$) of participants correctly understand that variation among individuals within a species is an important evolutionary mechanism and that complex structures such as the eye could have been formed by evolution. Of those participants agreeing with statement 15 ($n = 398$) however, 42.2% ($n = 168$) disagree with statement 18. This result appears to indicate that while these individuals understand that variation within a species is an important mechanism of evolution, they apparently disregard the role of variation in contributing to the formation of complex structures. Of those individuals who disagreed with statement 15 ($n = 398$), 39.2% ($n = 156$) disagreed with statement 18 as well. These individuals, representing 15.7% ($n = 156$) of the participant population, not only fail to grasp the importance of variation in the evolution of complex structures but likewise discount the idea that complex structures can be produced via evolution.

Collectively, participants possessed a 44.3% mean rate of understanding, a 39.4% mean misconception rate, and a 16.3% mean combined undecided or nonresponse rate in response to the five *Mechanisms of Evolution* statements. While 9.3% (*n* = 92) of participants expressed no misconceptions related to the five statements, 27.7% (*n* = 275) held one misconception; 31.3% (*n* = 311), two misconceptions; 22.2% (*n* = 220), three misconceptions; 8.5% (*n* = 85), four misconceptions; and 1.0% (*n* = 10) held misconceptions related to each of the five statements. Collectively, 90.7% of participants (*n* = 901) held one or more misconceptions related to the mechanisms of evolution statements.

Evidence Supporting Evolution

Although scientific evidence supporting biological evolution theory is abundant, diverse, and compelling, ranging from the fossil record to homology of DNA (Alters and Alters 2001; Futuyma 1998; Ridley 1996; Shermer 2006), this study revealed student participants possess high rates of misconceptions concerning selected evidences supporting biological evolution. Statements 20 through 23 address the opinions of student participants concerning evidence supporting evolution. Figure 5 illustrates the responses to each of these statements.

Responses from statement 20 ("There exists a large amount of evidence supporting the theory of evolution") revealed 36.1% of participants (*n* = 358) in agreement whereas 43.9% (*n* = 436) opted for the misconception. The most convincing evidence for the occurrence of evolution is the discovery of fossils of extinct organisms in older geological strata (Mayr 2001). Yet, student misconceptions abound concerning fossil evidence of evolution. Based on a perceived fossil record, student misconceptions accept the coexistence of humans and dinosaurs even though evidence indicates the two groups are separated by approximately 65,000,000 years (Alters and Alters 2001; Alters and Nelson 2002). Students in this study were no exception, as this misconception was prevalent in 33.6% (n = 334) of student participants (statement 22, "Scientific evidence indicates that dinosaurs and humans lived at the same time in the past"). A very small positive correlation of $r(981) = .09, p < .01$ was produced between statements 20 and 22 as only 17.8% (n = 177) of participants lacked misconceptions related to both statements. Of the participants agreeing with statement 20 (n = 358), 36.0% (n = 129) were in agreement with statement 22. Although these participants (n = 129) apparently are aware of the abundance of evidence supporting evolution theory, they are unaware--or choose to ignore--the evidence indicating the great expanse of time between the extinction of dinosaurs and the emergence of humans. Of those participants who disagreed with statement 20 (n = 436) and therefore do not claim a large amount of evidence exists supporting evolution, 33.3% (n = 145) agreed with statement 22, contending that scientific evidence indicates that dinosaurs and humans were contemporaries. These 145 individuals, holding to misconceptions associated with both statements 20 and 22, represent 14.6% of participants (N = 993). Conversely, 50.0% (n = 218) of individuals disagreeing with statement 20 (n = 436), also disagreed with statement 22. Although these students possess misconceptions concerning the abundance of evidence supporting evolutionary theory, they disavow the idea of dinosaurs and humans coexisting.

Correlation coefficients were produced between statement 20 and statements 2 ("The scientific methods used to determine the age of fossils and the Earth are reliable") and 4 (“The Earth is old enough for evolution to have occurred”). Statements 20 and 2 revealed a very small positive correlation of $r(984) = .10$, $p < .01$ with 28.3% ($n = 281$) of participants agreeing with both positive statements and 11.3% ($n = 112$) in disagreement with both statements. For this later group of participants, the failure to accept the existence of a large amount of evidence supporting the theory of evolution may at least partially be a direct result of their questioning the reliability of scientific dating methods. A medium positive correlation, $r(979) = .36$, $p < .01$, was discovered between participants’ responses to statements 20 and 4 with 27.9% ($n = 277$) agreeing with both positive statements whereas 20.1% ($n = 204$) disagreed with both statements. For those participants adhering to misconceptions associated with both statements 20 and 4, 29.4% ($n = 60$) also held to the misconception identified by statement 2. These 60 individuals, representing 6.0% of all participants, are consistent in their multiple misconceptions, denying the large volume of evidence supporting the theory of evolution while at the same time asserting that scientific dating methods are not reliable and the Earth is not old enough for evolution to have occurred.

Perhaps no area of evolution is more fraught with misconceptions than that of the evolutionary history of humans. Although biological evolution theory tells us that humans and modern apes evolved in present-day Africa from common primate ancestors some six million years ago (Smith and Sullivan 2007), a common misconception voiced by students is that humans evolved from monkeys, gorillas, or apes (Dagher and BouJaoude 1997; Lord and Marino 1993; Robbins and Roy 2007; Smith and Sullivan 2007). This study revealed 48.6% ($n = 482$) of student participants adhere to this misconception (statement 21, “According to the theory of evolution, humans evolved from monkeys, gorillas, or apes.") as opposed to 42.3% (n = 420) who did not. These results are comparable to a 1993 study of university students which found that 42.0% of students questioned stated humans evolved from monkeys (Lord and Marino 1993). For those students agreeing with statement 20 (n = 358), 34.4% (n = 123) disagreed with statement 21 indicating these individuals possess an accurate interpretation of both concepts. These 123 participants representing only 12.4% of all participants (N = 993) divulge a relatively high percentage of participants who possessed either one or both misconceptions related to this pair of statements. Of those participants agreeing with statement 20 (n = 358), 60.6% (n = 217) also agreed with statement 21. These participants apparently possess knowledge of the extent of evidence supporting the theory of evolution yet they hold the misconception that humans evolved from monkeys, gorillas, or apes through evolutionary processes. Similarly, of those participants who disagreed with statement 20 (n = 436), 51.1% (n = 223) also disagreed with statement 21. While these individuals fail to recognize the abundance of evidence supporting evolution, they correctly assert that humans did not evolve from monkeys, gorillas, or apes. Finally, of those participants who disagreed with statement 20 (n = 420), 43.1% (n = 181) agreed with statement 21 which indicates that these individuals claim both misconceptions associated with statements 20 and 21. Collectively, 74.2% (n = 737) of participants held at least one misconception related to statements 20 and 21, resulting in a medium positive correlation of $r(983) = .25$, $p < .01$.

Statement 23 ("The majority of scientists favor evolution over other explanations for life") yielded 45.5% (n = 452) agreement among participants with

32.8% ($n = 326$) in disagreement. Of those participants who agreed with statement 20 ($n = 358$), 59.5% ($n = 213$) also agreed with statement 23 while 27.7% ($n = 99$) disagreed, producing a medium positive correlation of $r(981) = .30$, $p < .01$ between statements 20 and 23. It is interesting that 10.0% of participants ($n = 99$) correctly indicate the existence of a large amount of evidence supporting evolution (statement 20) yet hold the misconception that the majority of scientists do not favor evolution over other explanations for life (statement 23). In addition, of those participants disagreeing with statement 20 ($n = 436$), 42.0% ($n = 183$) agreed with statement 23. These participants contend that a large amount of evidence supporting evolution is lacking while at the same time believe the majority of scientists favor evolution over other explanations for life. These two contradictory concepts seem to indicate a lack of understanding of the process of science in these 183 individuals who represent 18.4% of participants.

Participants possessed a 42.7% mean rate of understanding coupled with a 39.7% mean misconception rate in response to the four *Evidence Supporting Evolution* statements while 17.6% of participants per statement were undecided or did not respond. Expressing no misconceptions related to the four statements were 12.9% ($n = 128$) of participants while 35.0% ($n = 348$) held one misconception; 35.5% ($n = 352$), two misconceptions; 14.2% ($n = 114$), three misconceptions; and 2.4% ($n = 24$) held misconceptions related to each of the four statements. Collectively, 87.1% of participants ($n = 865$) held one or more misconceptions related to the four *Evidence Supporting Evolution* statements.

Summary

Out of a possible maximum index score of 115, student participants in this study (*N* = 993) earned a 70.34 (*SD* = 7.04) BEL-MIS for the 23 statements. Out of a possible maximum index score of 25.0, the SSMT category of five statements (1-5) produced a BEL-MIS of 15.61 (*SD* = 3.57) while the IE statements (6-10) yielded a mean score of 15.61 (*SD* =3.20), and the five ME statements (15-19), a 15.22 BEL-MIS (*SD* = 3.18). Out of a possible maximum index score of 20.0, the four NE category (statements 11-14) produced a BEL-MIS of 11.64 (*SD* = 2.26), while the four ESE category statements (20-23) resulted in a BEL-MIS of 12.25 (*SD* = 2.65). Analysis of results revealed that student participants produced a mean 43.9% rate of understanding, 39.1% misconception rate, and a combined 17.0% undecided and nonresponse rate for the 23 BEL Survey statements. Participants' mean rates of understanding for the individual concept categories included: SSMT, 46.8%; IE, 44.3%; NE, 41.5%; ME, 44.3%; and ESE, 42.7%, whereas the students' mean misconception rates per category were: SSMT, 35.2%; IE, 37.5%; NE, 43.8%; ME, 39.4%; and ESE, 39.7%.

Limitations of Study

Like all survey-based research, the results reported in Table 3 have limitations. Even though incomplete student surveys and those showing obvious indications of noncompliance with instructions were eliminated from the study, students' efforts varied in completing the survey in an accurate manner. Moreover, the survey was administered by the students' Biology I teachers whose attitudes concerning biological evolution may have influenced the proper administration of the survey as well as their students' attitudes and responses. In addition, varying degrees of exposure to evolution concepts from sources such as parents, churches, media, textbooks, and previous as well as current science and nonscience courses, may have influenced students' responses.

Further limitations of this study involve two variables associated with the student participants which were significantly different ($p < .05$) from the population from which they originated. First, analysis revealed that the 42 public high schools from which the student participants originated were not representative of the collective 474 public high schools within the study area in terms of urban-centric classification, $\chi^2(3, N = 42) = 8.0$, $p = .046$. Specifically, only 2.4% of participants' high schools were classified as residing in cities as opposed to 7.2% of public high schools within the study region, while 26.2% of participants' high schools compared with 17.7% of those of the study region were town designated (see Table 2). As a result, student participants' BEL-MIS compared to the urban-centric classification of students' schools may not be truly representative of the study region. Second, a statistically significant difference was identified between the percentage of ethnicities in the student participant population (see Table 1) when compared to those of all public high school students within the study region, $\chi^2(4, N = 997) = 12.2$, $p = .02$. As a result, student participants' BEL-MIS may not be truly representative of the study region in certain cases (IESNCES 2010c). Specifically, Black non-Hispanic students were under-represented in the study (3.3% as opposed to an expected 10.9%) as were Hispanic students (5.6% as opposed to an expected 11.2%). Conversely, White, non-Hispanic students were over-represented in the study (71.8% as opposed to an expected 56.4%).

Despite these possible limitations, it is important to note that the study sample was large and students who did participate in this study were diverse and represented a variety of high schools (e.g., small, large, rural, city). In addition, the types and prevalence of biological evolution misconceptions held by these students were consistent with data reported in the literature (Beardsley 2004; Bizzo 1994; Clough and Wood-Robinson 1985; Creedy 1993; Deadman and Kelly 1978; Demastes et al. 1995; Evans 2000; Geraedts and Boersma 2006; Halldén 1988; Jiménez-Aleixandre 1992; Jungwirth 1975; Kampourakis and Zogza 2007, 2008, 2009; Lawson and Thompson 1988; Palmer 1999; Pedersen and Halldén 1992; Prinou et al. 2008; Settlage 1994; Shtulman 2006; Spindler and Doherty 2009; Tamir and Zohar 1991).

Conclusion

"The single most important factor influencing learning is what the learner already knows" (Mintzes and Wandersee 1998, p. 81). This study explored what learners "already know" by investigating the prevalence of biological evolution-related misconceptions held by 993 Oklahoma public high school students prior to instruction in their initial high school biology course. Such misconceptions were prevalent within this population and the findings corroborates the literature that reports a strikingly high prevalence of biological evolution-related misconceptions in students at all levels, from elementary pupils to university science majors (Gregory 2009), indicative of a pervasive problem in evolution education. In order for science educators to eliminate and replace their students' misconceptions with accurate science-based, biological evolution concepts, the following suggestions are offered.

First, as misconceptions may preclude an accurate understanding of biological evolution concepts, student misconceptions brought into the classroom must be identified. The National Research Council (NRC) reports that "research on students' conceptual misunderstanding of natural phenomena indicates that new concepts cannot be learned if alternative models that explain a phenomenon already exist in the learner's mind" (NRC Committee on Undergraduate Science Education 1997, p. 28). Research involving student learning in the high school biology classroom suggests that there is a complicated synergism affecting the learning of evolution which includes the learner's prior conceptions related to evolution (Alters and Nelson 2002). In order for students to gain an accurate understanding of biological evolution concepts, students' misconceptions must be addressed within the classroom. If students' initial understanding is not engaged, they may fail to grasp the new concepts that are taught, or they may learn them for purposes of a test but revert to the preconceptions otherwise (Bransford et al. 2000). One means of identifying students' misconceptions is for the teacher to use an assessment tool (Wescott and Cunningham 2005). For example, the lead author administers the BEL Survey to students in his university nonmajor's biology course during the initial week of class and then adapts instruction based upon the results of the survey. Post-survey instruction typically includes a class discussion of the students' collective misconceptions. (See Cunningham and Wescott 2009 for a discussion of available assessment tools).

Second, sources of misconceptions must be identified. The scientific community regards evolution as a vital part of science education (NAS 2008) yet evolutionary theory is one of the most commonly misunderstood areas in biology (Gregory 2009). It is therefore imperative to identify sources of biological evolution misconceptions before one can effectively employ teaching practices to ameliorate misconceptions. Understanding students' perceptions of evolutionary theory requires an investigation into not only the sources of misconceptions concerning evolution (Modell et al. 2005; Novak 2002; NRC 1996; Wescott and Cunningham 2005) but the variety of factors that might influence the development of such perceptions (Hokayem and BouJaoude 2008). Sources from which these misconceptions arise are varied and can be complex (Modell et al. 2005). Such sources include: (a) from-experience misconceptions, (b) self-constructed misconceptions, (c) taught-and-learned misconceptions, (d) vernacular misconceptions, and (e) religious and myth-based misconceptions (Alters and Nelson 2002).

Once identified, teachers must address strategies for eliminating misconceptions that students bring into the classroom. Although a detailed description is beyond the scope of this paper, researchers have suggested several means of addressing student misconceptions about biological evolution in the classroom. These strategies include the constructivist approach of conceptual change (Alters and Nelson 2002; Cunningham and Wescott 2009; Lawson 1994); historically rich curriculum with paired problem-solving instruction (Alters and Nelson 2002; Cunningham and Wescott 2009; Jensen and Finley 1996); concept maps (Alters and Nelson 2002; Cunningham and Wescott 2009; Liu 2004; Mintzes et al. 2001; Trowbridge and Wandersee 1994); and student-centered discussions (Alters and Nelson 2002).

Most importantly, science teachers, who welcome those students burdened with biological evolution misconceptions into their classrooms, must be well-grounded in evolutionary theory in order to identify such misconceptions and help replace them with accurate, science-based concepts. Unfortunately this is not always the case. A recent study involving the Biology I teachers of this current study’s high school students revealed a disturbing 72.9% average rate of understanding of biological evolution-related concepts and a 23.0% misconception rate (combined 4.0% undecided and nonresponse mean; Yates and Marek 2011). Disturbingly then, this present study's student participants, possessing a 43.9% rate of understanding coupled with an average misconception rate of 39.1% , entered their initial high school biology course to be taught by teachers who produced a mean 23.0% misconception rate on the same instrument. The question then begs: How many of these students' will complete their initial biology course with their misconceptions still intact? In addition, high school biology teachers must actually teach those biological evolution concepts as mandated by national and state curriculum standards and eliminate nonscience explanations within the science classroom (see Marek et al. 2006). Weld and McNew (1999) found that 33.0% of Oklahoma public school life-science teachers in their study (N = 224) placed little or no emphasis on evolution while at the same time approximately 25.0% placed moderate or strong emphasis on creationism.

Identification, elimination, and replacement of student misconceptions of biological evolution during high school science should begin in--and be a priority of--college and university science education programs. In particular, increased focus should be placed on preservice science teachers' evolution education. Research indicates that completion of an evolution course by preservice science teachers is a powerful predictor of advocacy of evolution, as well as classroom-time devoted to learning about evolution (Berkman et al. 2008; Donnelly and Boone 2007). Moreover teachers are more likely to integrate evolution concepts into their courses as a unifying theme (Berkman and Plutzer 2010). Such an emphasis is vitally important for identifying and reducing the number of biological evolution misconceptions that pervade high school biology courses. Many students will have the opportunity to reinforce previously learned biological evolution concepts and expand their knowledge in subsequent high school and college science courses. For some students, however, the only formal exposure to biological evolution in high school will be in their initial high school biology course. This initial biology course is the only high school science class for 21% to 25% of U.S. high school graduates (Berkman and Plutzer 2011) and the sole academic exposure to evolution for those who choose not to pursue a post-secondary education. Therefore, strategies must be in place to ensure that introductory biology teachers not only possess a thorough working knowledgeable of biological evolution but strategies for recognizing, addressing, and eliminating student-held misconception of evolution as well.

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Table 1

Student Profile

Demographic Variable	Variables	*n*	%*	BEL-MIS
Gender	Female	512	51.6	69.94
	Male	479	48.2	70.77
	No response	2	0.2	-
Grade	Freshman	237	23.9	70.29
	Sophomore	716	72.1	70.26
	Junior	27	2.7	73.04
	Senior	8	0.8	71.50
	No response	5	0.5	-
Ethnicity	American Indian or Alaska Native	157	15.8	70.54
	Asian or Pacific Islander	18	1.8	71.94
	Black, non-Hispanic	33	3.3	69.76
	Hispanic	56	5.6	69.12
	White, non-Hispanic	713	71.8	70.35
	No response	16	1.6	-

Table 1 (continued).

Demographic Variable	Variables	*n*	%*	BEL-MIS
Knowledge self-rating	Excellent	36	3.6	70.08
	Good	146	14.7	72.55[ab]
	Average	433	43.6	70.56
	Fair	224	22.6	69.49[a]
	Poor	143	14.4	68.92[b]
	No response	11	1.1	-
Average daily membership	4451.85 – 485.57	284	28.6	70.57
	482.10 – 242.95	233	23.5	69.70
	242.30 – 134.10	260	26.2	69.96
	132.10 – 78.11	126	12.7	71.72
	77.73 – 14.85	90	9.1	70.44
Urban centric classification	City	25	2.5	69.92
	Suburban	69	7.0	71.56
	Town	407	41.0	70.21
	Rural	492	49.5	70.30

Note. *BEL-MIS* = BEL Survey mean index score. Maximum BEL-MIS is 115. Those BEL-MIS possessing the same subscript are significantly different at $p < 0.05$.

*Percent may not total 100.0% due to rounding.

Table 2

Public High School Profile

Demographic variable	Variable range	Percentage of High Schools	
		Participant HS (N = 42)	Study area HS (N = 474)
Average daily membership*[a]	4461.85 – 485.57	26.2	20.0
	482.10 – 242.95	21.4	20.0
	242.30 – 134.10	21.4	20.0
	132.10 – 78.11	14.3	20.0
	77.73 – 14.85	16.7	20.0
Urban-centric classification**[b]	City	2.4	7.2
	Suburban	7.1	5.7
	Town	26.2	17.7
	Rural	64.3	69.4

Note. *HS* = high school. Participant high schools contain study participants whereas study area high schools are the total number of high schools within the study area.

[a]Average daily membership (ADM) is the aggregate membership of a school during a reporting period (normally a school year) divided by the number of days school is in session during this period. (IESNCES, 2010a).

[b]Urban-centric classification (IESNCES, 2010b).

*p > .05. Difference is not significant. X^2 (4, N = 42) = 4.29, p = .37.

**p < .05. Difference is significant. X^2 (3, N = 42) = 8.0, p = .046.

Table 3

BEL Survey Statement Percent Student Response

#	Category	Statement	Student % Response*					
			1	2	3	4	5	6
1	SSMT1	A scientific theory that explains a natural phenomenon can be classified as a "best guess" or "hunch"[a]	12.9	37.1	21.3	12.7	15.7	0.3
2	SSMT2	The scientific methods used to determine the age of fossils and the earth are reliable.	22.6	50.7	13.5	7.7	5.4	0.2
3	SSMT3	According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms.	9.4	12.0	19.5	16.3	41.9	0.9
4	SSMT4	The earth is old enough for evolution to have occurred.	27.9	28.9	12.5	19.2	10.9	0.6
5	SSMT5	Evolution cannot be considered a reliable explanation because evolution is only a theory.	29.8	25.0	21.3	12.9	10.7	0.3
6	IE1	Evolution always results in improvement. [a]	6.7	23.3	28.7	25.4	14.3	1.6
7	IE2	Members of a species evolve because of an inner need to evolve.[a]	10.3	28.1	22.3	17.8	21.0	0.5
8	IE3	Traits acquired during the lifetime of an organism--such as large muscles produced by body building--will not be passed along to offspring.	30.5	25.4	20.4	15.2	8.1	0.4
9	IE4	If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation. [a]	10.2	30.1	21.9	12.5	24.5	0.9

Table 3 (continued).

#	Category	Statement	Student's % Response*					
			1	2	3	4	5	6
10	IE5	Evolution cannot cause an organism's traits to change within its lifetime.	14.9	22.2	26.4	16.8	18.7	1.0
11	NE1	New traits within a population appear at random.[b]	9.4	31.8	26.1	15.5	16.5	0.7
12	NE2	Individual organisms adapt to their environments.	47.8	32.3	9.0	4.4	5.4	1.0
13	NE3	Evolution is a totally random process.	9.7	16.2	25.7	25.8	22.5	0.2
14	NE4	The environment determines which traits are best suited for survival.	26.1	33.7	16.5	11.0	11.9	0.8
15	ME1	Variation among individuals within a species is important for evolution to occur. [a]	10.5	29.6	19.7	9.0	30.9	0.3
16	ME2	"Survival of the fittest" means basically that "only the strong survive."[b]	35.6	26.9	17.3	13.6	6.3	0.2
17	ME3	The size of the population has no effect on the evolution of a species[a]	10.8	19.3	31.9	23.0	14.8	0.2
18	ME4	Complex structures such as the eye could have been formed by evolution.	11.6	25.0	18.1	26.9	17.9	0.5
19	ME5	Only beneficial traits are passed on from parent to offspring.	8.8	21.8	25.6	33.5	9.3	1.0
20	ESE1	There exists a large amount of evidence supporting the theory of evolution. [a]	12.9	23.2	20.0	23.9	19.2	0.8
21	ESE2	According to the theory of evolution, humans evolved from monkeys, gorillas, or apes.	23.1	25.5	11.9	30.4	8.9	0.3
22	ESE3	Scientific evidence indicates that dinosaurs and humans lived at the same time in the past. [a]	13.1	20.5	19.1	27.9	18.7	0.6

Table 3 (continued).

#	Category	Statement	Student's % Response*					
			1	2	3	4	5	6
23	ESE4	The majority of scientists favor evolution over other explanations for life.	18.2	27.3	20.9	11.9	21.1	0.5

Note: *SSMT* = science, scientific methodology and terminology; *IE* = intentionality of evolution; *NE* = nature of evolution; *ME* = mechanisms of evolution; *ESE* = evidence supporting evolution; *1* strongly agree; *2* somewhat agree; *3* somewhat disagree; *4* strongly disagree; *5* undecided/never heard of it; *6* no response. Shaded areas indicate percentage of participants accepting the statement-related misconception.

*Percent response may not total 100.0% due to rounding.

[a]Statement adapted from Cunningham and Wescott (2009).

[b]Statement taken directly from Cunningham and Wescott (2009).

Table 4

Interaction Between Student Responses to Selected BEL Survey Statements

Statement	Interaction statement	Agree with statement*			Disagree with statement*			Undecided about statement*		
		%A	%D	%U	%A	%D	%U	%A	%D	%U
Science, scientific method and terminology										
1	5	57.2	35.7	7.1	15.5	82.8	1.7	0.0	0.0	100.0
2	4	91.1	7.1	1.8	50.0	40.0	10.0	0.0	0.0	0.0
Intentionality of evolution										
6	7	36.8	63.2	0.0	18.5	79.6	1.9	0.0	0.0	100.0
	9	42.1	57.9	0.0	23.6	74.6	1.8	0.0	100.0	0.0
	19	15.8	84.2	0.0	5.5	94.5	0.0	0.0	100.0	0.0
7	8	64.7	23.5	11.8	89.3	10.7	0.0	100.0	0.0	0.0
	10	58.8	23.5	17.7	87.5	10.7	1.8	100.0	0.0	0.0
10	8	88.7	11.3	0.0	60.0	40.0	0.0	50.0	0.0	50.0
Nature of evolution										
11	13	44.0	54.0	2.0	13.0	82.6	4.4	0.0	100.0	0.0
	14	94.0	6.0	0.0	82.6	17.4	0.0	66.7	0.0	33.3
12	14	85.3	11.8	2.9	92.9	7.1	0.0	0.0	0.0	0.0
13	14	92.0	8.0	0.0	89.8	8.2	2.0	50.0	50.0	0.0

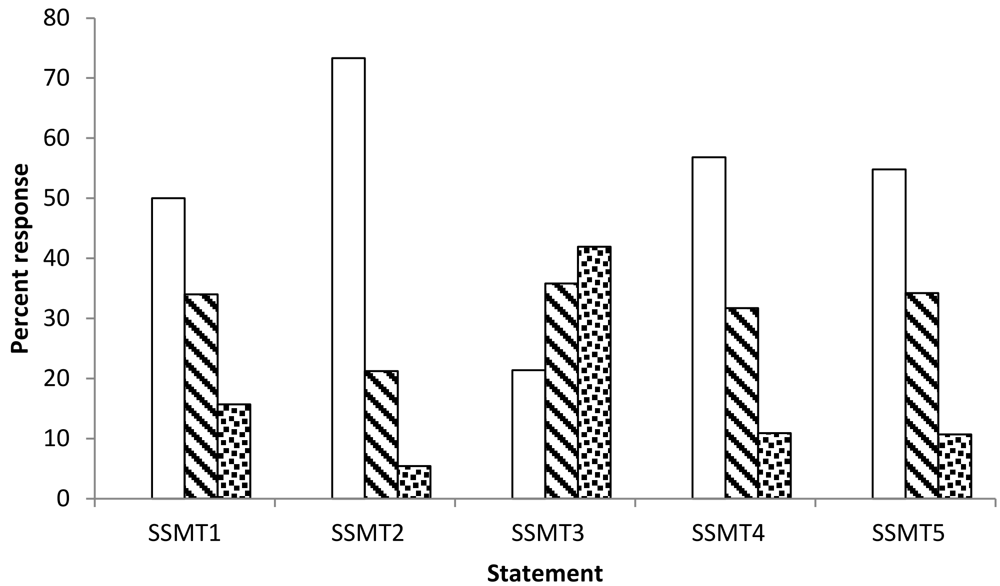
Table 4 (continued).

Statement	Interaction statement	Agree with statement*			Disagree with statement*			Undecided about statement*		
		%A	%D	%U	%A	%D	%U	%A	%D	%U
Mechanisms of evolution										
15	9	23.9	76.1	0.0	85.7	14.3	0.0	0.0	50.0	50.0
	16	37.3	62.7	0.0	85.7	14.3	0.0	0.0	100.0	0.0
	17	7.5	92.5	0.0	28.6	71.4	0.0	0.0	50.0	50.0
	18	62.7	32.8	4.5	14.3	71.4	14.3	0.0	50.0	50.0
	19	3.0	97.0	0.0	42.9	57.1	0.0	50.0	50.0	0.0
Evidence supporting evolution										
20	2	89.8	10.2	0.0	45.8	54.2	0.0	33.3	66.7	0.0
	4	98.0	0.0	2.0	45.8	50.0	4.2	33.3	33.3	33.3
	21	14.3	79.6	6.1	41.7	58.3	0.0	0.0	100.0	0.0
	22	14.6	81.2	4.2	41.7	50.0	8.3	66.7	0.0	33.3
	23	79.6	12.2	8.2	75.0	25.0	0.0	33.3	0.0	66.7

Note. Table 4 compares participants' interaction statement responses to those of a specified statement. *A* = agreed; *D* = disagreed; *U* = undecided.
Example: Of those participants who agreed with statement 1, 57.2% disagreed with statement 5.

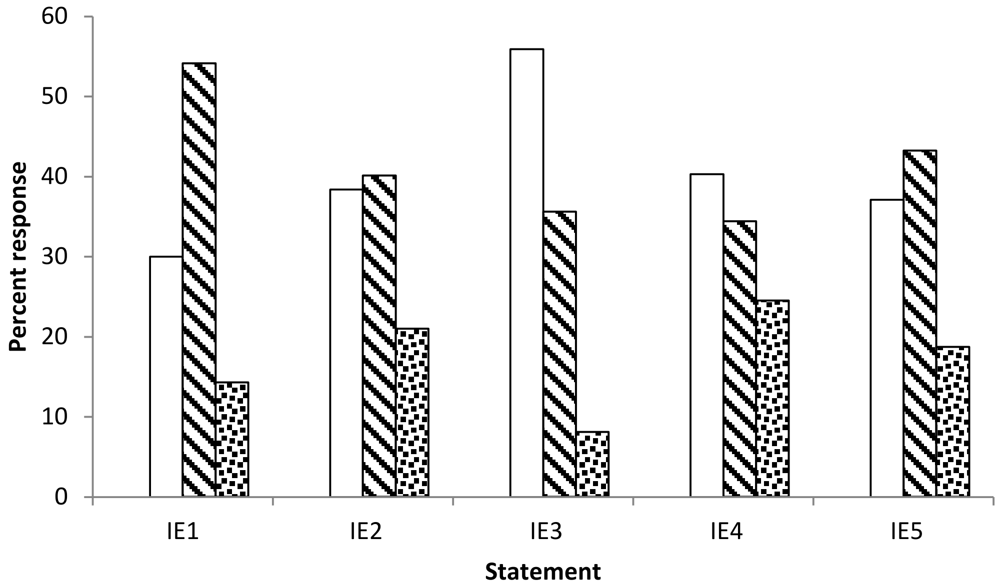
*Percent response may not total 100 due to rounding.

Figure 1. Percent response to science, scientific method and terminology statements.



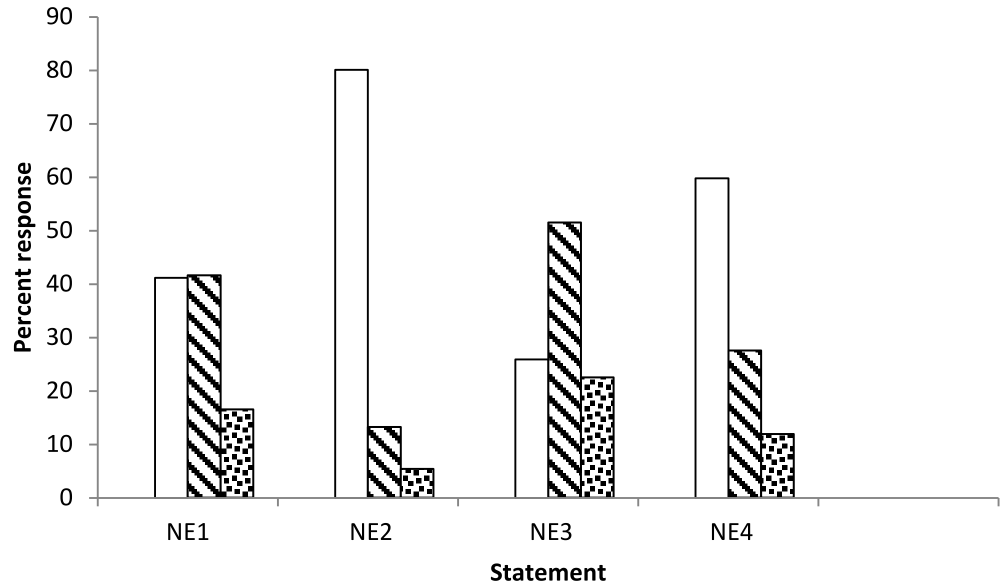
Clear bar = "strongly agree/somewhat agree"; *diagonal bar* = "strongly disagree/somewhat disagree"; *dotted bar* = "undecided/never heard of it"

Figure 2. Percent response to intentionality of evolution statements.



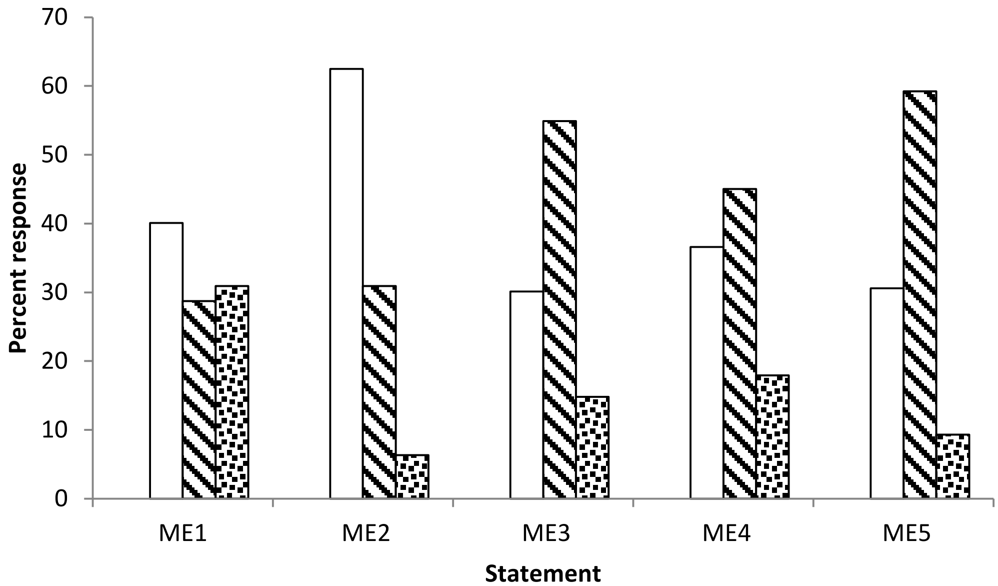
Clear bar = “strongly agree/somewhat agree”; *diagonal bar* = “strongly disagree/somewhat disagree”; *dotted bar* = “undecided/never heard of it”

Figure 3. Percent response to nature of evolution statements.



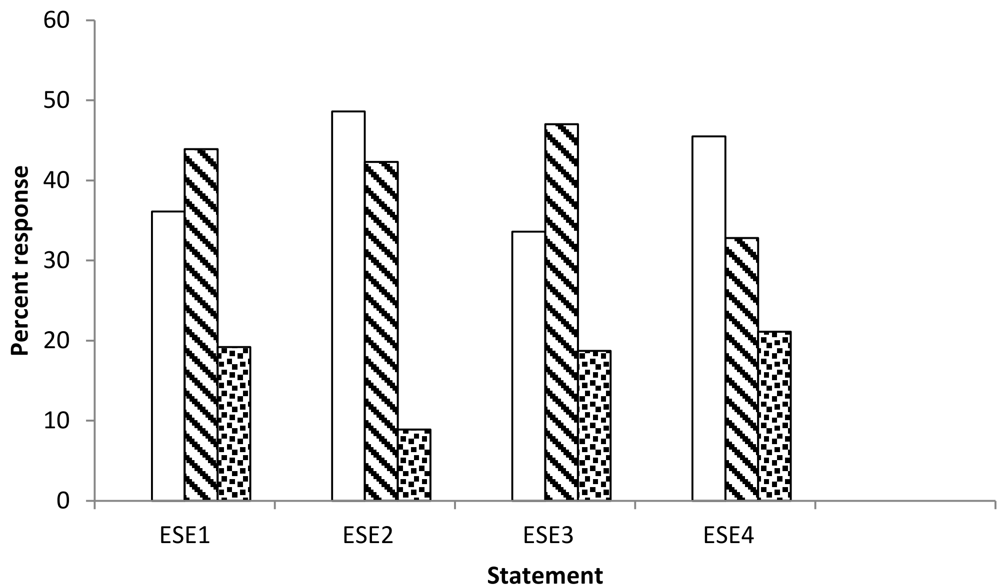
Clear bar = “strongly agree/somewhat agree”; *diagonal bar* = “strongly disagree/somewhat disagree”; *dotted bar* = “undecided/never heard of it”

Figure 4. Percent response to mechanisms of evolution statements.



Clear bar = "strongly agree/somewhat agree"; *diagonal bar* = "strongly disagree/somewhat disagree"; *dotted bar* = "undecided/never heard of it"

Figure 5. Percent response to evidence supporting evolution statements.



Clear bar = “strongly agree/somewhat agree”; *diagonal bar* = “strongly disagree/somewhat disagree”; *dotted bar* = “undecided/never heard of it”

MANUSCRIPT III

Teachers Teaching Misconceptions: A Study of Factors Contributing to High School Biology Students' Acquisition of Biological Evolution-related Misconceptions

This manuscript is prepared for submission to the peer-reviewed *Journal of Research in Science Teaching* and is the third of three manuscripts prepared for a journal-ready doctoral dissertation.

Abstract

Research has revealed that high school students matriculate to college holding misconceptions related to biological evolution. These misconceptions interfere with students' abilities to grasp accurate scientific explanations and serve as fundamental barriers to understanding evolution. Because the scientific community regards evolution as a vital part of science education, it is imperative that students' misconceptions are identified and their sources revealed. The foci of this study was to (a) identify the types and prevalences of biological evolution-related misconceptions held by high school biology teachers and their students and (b) identify those factors which contribute to student acquisition of such misconceptions, with particular emphasis given to the role of the teacher. Thirty-five public high school Biology I teachers and their collective 536 students during the 2010 – 2011 academic year served as this study's unit of analysis. Participants represented 32 public high schools. The *Biological Evolution Literacy Survey* (Yates & Marek, 2011), which presents 23 biological misconception statements grouped into five categories, served as the research tool for identifying participants' misconceptions, calculating conception index scores, and collecting demographic data. Analyses revealed that students typically exit Biology I more confident in their evolution knowledge but holding greater numbers of misconceptions than they initially possessed. Also revealed were significant relationships between student acquisition of misconceptions and teachers' bachelor's degree field, terminal degree, and hours dedicated to evolution instruction. Implications associated with this study are discussed.

Keywords: biology education, biology teachers, evolution education, misconception, Oklahoma, public high school, students

Introduction

A *misconception* is defined as “a perception of phenomena occurring in the real world which is not consistent with the scientific explanation of the phenomena” (Modell, Michael, & Wenderoth, 2005, p. 20). Numerous studies reveal that high school zstudents enter college biology courses holding misconceptions related to biological evolution (Bishop & Anderson, 1990; Brumby, 1984; Wescott & Cunningham, 2005; Wilson, 2001). These misconceptions range from minor misunderstandings to complete theory rejection (Alters & Alters, 2001; Dagher & BouJaoude, 2005; Evans, 2001; Mazur, 2004; McComas, 2006; Sadler, 2005) and are typically complex and strongly held, serving as fundamental barriers which interfere with students’ abilities to understand accurate scientific explanations concerning evolution that are presented in class (Bishop & Anderson, 1990; Brumby, 1984; Ferrari & Chi, 1998; Jiménez & Fernández-Pérez, 1987; Meir, Perry, Herron, & Kingsolver, 2007; Wescott & Cunningham, 2005; Wilson, 2001)

Misconceptions are held by novices and experts alike (Palmquist & Finley, 1997). It is therefore logical to assume that teachers, too, hold a range of misconceptions (Kikas, 2004). A number of studies revealed that many teachers, including those with experience, operate while holding misconceptions about various biological concepts (e.g., Affanato, 1986; Bishop & Anderson, 1990; Brumby, 1984; Chinsamy & Plagányi, 2007; Clough & Wood-Robinson, 1985; Demastes, Good, & Peebles, 1995; Greene, 1990; Nehm & Schonfeld, 2007; Osif, 1997; Settlage, 1994; Yip, 1998). In fact, research indicates that teachers adhere to many of the same biological evolution misconceptions as do their students (Bishop & Anderson, 1990;

Brumby, 1984; Demastes et al., 1995; Nehm & Schonfeld, 2007; Settlage, 1994). As Nehm and Schonfeld concluded, "one cannot assume that biology teachers with extensive backgrounds in biology have an accurate working knowledge of evolution, natural selection, or the nature of science" (p. 716).

The scientific community regards evolution as a vital part of science education (National Academy of Sciences, 1998) yet evolutionary theory is one of the most commonly misunderstood areas of biology (Gregory, 2009). In order to ensure that students complete their science courses with accurate understandings and working knowledge of biological evolution, it is imperative to identify sources of confusions concerning evolution (Modell et al., 2005; National Research Council [NRC], 1996; Novak, 2002; Wescott & Cunningham, 2005). Understanding both students' and teachers' conceptions of the theory of evolution requires an investigation into the variety of factors that might influence the development of such conceptions (Hokayem & BouJaoude, 2008). Much recent research concerning misconceptions in general, and misconceptions of biological evolutionary theory in particular, attempts to reveal causative agents. This research has determined that sources from which these conceptual difficulties arise are varied and complex (Modell et al., 2005). A question of particular interest in this study is: Are high school biology teachers sources of students' biological evolution misconceptions?

Taught-and-learned misconceptions are misconceptions that have been taught by parents, teachers, and others or unconsciously learned from fiction (Alters & Nelson, 2002). In instructor-centered teaching, the instructor determines, primarily from tradition and disciplinary content, exactly what is to be taught and how it should be taught (Alters & Nelson, 2002). For teachers possessing biological evolution-related misconceptions, this suggests these teachers may convey those misconceptions to their students through inaccurate teaching (Alters & Nelson, 2002; Barrass, 1984; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Fisher, 2004; Haidar, 1997; Jarvis, Pell, & McKeon, 2003; Lawrenz, 1986; Mohapatra & Bhattacharyya, 1989; Sanders, 1993; Wandersee, Mintzes, & Novak, 1994; Yip, 1998), critically impeding student conceptual development of accurate scientific explanations (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Fisher, 2004; Jarvis et al., 2003; Kikas, 2004). Evidence therefore indicates there is great potential for teachers' biological evolution-related misconceptions to be taught to their students (Fisher, 2004; Wood-Robinson, 1994).

In order to assess the role of biology teachers in student acquisition of biological evolution-related misconceptions, Oklahoma public high school introductory biology teachers and their students were surveyed. The teachers' initial survey was followed by a pair of surveys administered to students in a single section of each teacher's Biology I course, both prior to and following mandated instruction in biological evolution concepts. The purpose of this study was to: (a) identify biological evolution misconceptions in the teacher and student populations, (b) determine the rate of change in students' misconceptions from pre- to post-instruction, and (c) identify factors that contribute to student acquisition of biological evolution misconceptions, including--but not limited to--variables associated with the teachers. While no claim is made that the results of this study, confined to public high schools within the state of Oklahoma, represent those of the entire country or other geographical regions, the findings are relevant and do contribute to the biological evolution misconception literature.

Method

Context

State science standards are the basis for what teachers teach and students learn and thereby establish the foundation for states' desired science education outcomes (Moore, 2009). The state of Oklahoma sets academic standards and assessments aligned to those standards. The Oklahoma State Department of Education's (OSDE) *Priority Academic Student Skills (PASS;* OSDE, 2009a) was developed in 1993 based on the *National Science Education Standards* (*NSES*; NRC, 1996) and the *Benchmarks for Scientific Literacy* by the American Association for the Advancement of Science (1993). *PASS* science standards present a framework for what students should know, understand, and be able to do in the natural sciences (NRC, 1996). High school Biology I possesses several *PASS* content standards that emphasize biological evolution-related concepts, which teachers should be thoroughly knowledgeable and should accurately teach to their students in Biology I. The *Oklahoma End-of-Instruction Biology I Alignment Blueprint* (OSDE, 2008-2009) calls for approximately 28 to 39% of the test to cover biological evolution-related concepts. *PASS* biological evolution-related standards were a primary reference in the development of both teacher and student survey instruments employed in this study.

Participants and Course

Participants in this study included 35 public high school biology teachers (17 males and 18 females) and their respective high school students ($N = 536$) enrolled in one Biology I course section taught by the teacher. Teachers were employed on a full-time basis during the 2010-2011 academic year by a collective 32 (6.8%) of the 474 public high schools (OSDE, 2009b) located within the state of Oklahoma, which served as the study region. For the purposes of this study, a high school is defined as a secondary school offering any combination of grades 9 through 12. All teacher participants possessed a current Oklahoma state teaching license obtained by meeting state licensure criteria (Oklahoma State Board of Education, 2010). These criteria included a minimum of a bachelor's degree and passing scores on state certification tests. All teacher participants were certified to teach biological sciences within the state of employment and taught at least one Biology I section at the high school level during the 2010-2011 academic year. Each potential teacher participant who met the study's criteria and volunteered to participate was presented with an *Informed Consent to Participate in a Research Study* form approved by the researchers' university Office of Human Research Participant Protection.

Student participants included 536 public high school students (287 females, 249 males) enrolled during the 2010-2011 academic year in one of the study's public high schools. Beginning in the fall of 2010, all student participants were first-time enrollees in a Biology I course taught by one of the 35 teacher participants. Biology I, a core curriculum course that is required for high school graduation (OSDE, 2009c), is typically taken by freshmen and sophomore students. Biology I investigates content, concepts, and principles of major themes in the biological sciences, including biological evolution (OSDE, 2009a) and serves as the prerequisite course for subsequent biology courses students may take (OSDE, 2009c). Students' participation involved regular classroom instruction activities administered by the teacher participants. Since the researcher did not interact with the students they were not required by the researcher's Internal Review Board to complete an *Informed Consent to Participate in a Research Study* form.

Instrumentation

To identify teacher and student participants' knowledge structure and misconceptions about biological evolution, an anonymous survey was developed called the *Biological Evolution Literacy Survey* (BEL Survey; Yates & Marek, 2011, p. 32-33). Prospective teacher participants were contacted via a recruitment letter with those who volunteered for the study completing the teacher version of the BEL Survey in May, 2010. These teacher participants were instructed to administer the student pre-instruction version of the BEL Survey to students in one Biology I course section within the initial week of the fall 2010 semester. By administering the survey as early as possible in the course, teacher and curriculum influences on students' knowledge and opinions related to the BEL Survey statements were limited. In addition, by surveying students in only one Biology I section, peer influence was reduced. Subsequently, teachers were instructed to administer an identical post-instruction student BEL Survey either following instruction in biological evolution concepts or at the completion of the course.

With permission, the BEL Survey was modeled after Cunningham and Wescott's 2009 survey which was adapted from Almquist and Cronin (1988) with additions from Wilson (2001), and Bishop and Anderson (1986, 1990). The purpose of Cunningham and Wescott's 2009 study was to identify the common misconceptions held by undergraduate students and attempt to explain the reasoning behind those misconceptions. In addition, Cunningham and Wescott were interested in assessing how students' opinions and understanding of evolutionary theory may have changed in the interim since the 1988 Almquist and Cronin study which attempted to identify college and university students' basic knowledge concerning the processes of evolution as well as their opinions on science and religion issues.

The BEL Survey is composed of two sections, the demographics section and the survey section. While the survey sections were identical for teacher and student participants, the demographics sections varied. Demographic data requested from teacher participants included gender, terminal degree, bachelor's degree major, years of teaching experience, college education emphasis on evolution, and self-rating of evolution knowledge (see Table 1). Demographic data requested for students included, gender, ethnicity, grade level, self-rating of knowledge of evolution, and indication as to whether the student had previously enrolled in a Biology I course (see Table 2). Any student whose survey indicated previous enrollment in a Biology I course was omitted from the study. In addition, three questions were posed which allowed matching of pre- and post-instruction BEL Survey responses to the same student while still maintaining anonymity.

The survey section of the BEL Survey asked both teacher and student participants to respond to whether they strongly agree, somewhat agree, somewhat disagree, strongly disagree, or have no opinion ("undecided/or never heard of it") on 23 statements related to biological evolution-related misconceptions. During data analysis, two methods of scoring responses were used. First, the responses "strongly agree" and "somewhat agree" were combined, indicating participant agreement with the statement.

Likewise, the responses “strongly disagree” and “somewhat disagree” were combined, indicating participant disagreement with the statement. Second, a biological evolution misconception scoring index for the statements was created by Likert scaling of responses with answers to statements indicative of a low acceptance of an evolution concept (high acceptance of the associated misconception) receiving low scores and responses to statements indicative of a high acceptance of an evolution concept (nonacceptance of misconception) receiving high scores. For statements in which agreement indicated a nonacceptance of the associated misconception (statements 2, 4, 8, 10, 11, 14, 15, 18, 20, 23), index scoring was as follows: (a) strongly agree, score of 5; (b) somewhat agree, 4; (c) undecided/ never heard of it, 3; (d) somewhat disagree, 2; (e) strongly disagree, 1; and (f) no response, 0. For statements in which agreement indicated a high acceptance of the associated misconception (statements 1, 3, 5, 6, 7, 9, 12, 13, 16, 17, 19, 21, 22), index scoring was as follows: (a) strongly agree, score of 1; (b) somewhat agree, 2; (c) undecided/never heard of it, 3; (d) somewhat disagree, 4; (e) strongly disagree, 5; and (f) no response, 0. The possible range of BEL Survey index scores was 0 to 115 with a score of 115 representing the highest level of understanding of those evolution concepts revealed by the BEL Survey coupled with a lack of associated misconceptions whereas lower indices represented lower levels of understanding combined with higher levels of misconceptions. In addition, a simple count of the number of misconceptions revealed by responses to the 23 BEL Survey statements was conducted for both teacher and student participants.

Cunningham and Wescott’s (2009) survey instrument on which the BEL Survey is modeled contained 24 statements classified into four categories: (a) evolutionary theory, (b) scientific facts, (c) process of evolution, and (d) language of science. For the present study, Cunningham and Wescott's four-category classification was modified into five categories of biological evolution-related misconceptions that are commonly employed in the literature (e.g., Alters & Alters, 2001; Bishop & Anderson, 1990; Greene, 1990; Gregory, 2009; Jensen & Finley, 1996; Wandersee et al., 1994; Wescott & Cunningham, 2005; Wilson, 2001). These misconception categories include: (a) science, scientific methodology and terminology (SSMT); (b) intentionality of evolution (IE); (c) nature of evolution (NE); (d) mechanisms of evolution (ME); and (e) evidence supporting evolution (ESE). While five biological evolution-related misconception statements were identified or developed for each of the SSMT, IE, and ME categories, four such statements were identified or developed for each of the NE and ESE categories. The resulting 23 statements were subsequently included in the BEL Survey (see Table 3) whereas category identification was omitted. While two BEL Survey statements (11 and 16) were acquired directly and eight statements (1, 6, 7, 9, 15, 17, 20, 22) were adapted from Cunningham and Wescott's survey, the remaining 13 statements (2, 3, 4, 5, 8, 10, 12, 13, 14, 18, 19, 21, 23) were developed through an extensive search of biological evolution misconception literature. Shaded regions located in the percent response columns of Table 3 identify responses which indicate participant adherence to the related statement misconception.

Results

Participant Demographics

Table 1 presents the teacher participant profile. Gender was evenly distributed with 17 males and 18 females. While all teacher participants possessed bachelor's degrees, 37.1% (n = 13) held graduate degrees as well. Biology bachelor's degrees were held by 37.1% of the participants (n = 13) while science education degrees, nonbiology science degrees, and non-science degrees were fairly evenly distributed among the remaining participants, ranging from 17.1 to 22.9%. Prior to this study, 20.0% (n = 7) of the teacher participants had completed five or fewer years of teaching experience; 31.4% (n = 11) ten or fewer years teaching experience; and 31.4% (n = 11) had accumulated over 20 years of experience in the classroom. When asked to identify the emphasis given to evolution in their college education, 48.6% (n = 17) of participants indicated that evolution was either highly or moderately emphasized while an identical 48.6% (n = 17) noted the emphasis given to evolution was either slight or non-existent. In rating their knowledge of evolution, 68.6% (n = 24) contended their knowledge of evolution was either excellent or good while 31.4% (n = 11) maintained an average or fair knowledge of evolution. None of the teacher participants considered their knowledge of evolution to be poor.

Table 2 presents the student participant profile. Females comprised 53.5% (n = 287) of the student participants with males the remaining 46.5% (n = 249). The majority of student participants were sophomores (73.5%, n = 394) with freshmen accounting for 24.4% (n = 131). White non-Hispanic student participants were the majority ethnic group (72.8%, n = 390) whereas students of Asian or Pacific Islander descent were in the minority, representing only 1.7% (n = 9) of student participants.

Public High School Variables

Analyses were conducted to identify any significant differences ($p < .05$) among variables related to the 32 public high schools representing the study's teacher and student participants when compared to the 474 public high schools located within the study area. A comparison between the two sets of schools focused on two variables: (a) distribution of student average daily membership (ADM; Institute of Education Sciences National Center for Educational Statistics [IESNCES] 2010a); and, (b) urban-centric classification (IESNCES, 2010b). A chi-square goodness-of-fit statistical analysis revealed no significant difference between the two high school groups for ADM distribution, χ^2 (4, N = 32) = 8.32, $p > .05$, but did reveal a significant difference in urban-centric classification, χ^2 (3, N = 32) = 14.14, $p < .05$ (see Table 4). These results indicate that the public high schools from which teacher and student participants originated were representative of the collective public high schools within the study area in ADM distribution but not in urban-centric classification. A 16.75 confidence interval at a 95% confidence level was determined for the sample of high schools containing study participants (n = 32) compared to the total number of public high schools (N = 474) located within the study area.

Comparison of Students' Pre- and Post-instruction BEL Survey Results

Cronbach's alpha of 0.848 was identified for the 23 statement BEL Survey which indicates that the internal reliability of the survey is acceptable. Additionally, if any one statement is deleted, the reliability coefficient does not decrease by more than 0.014, thus maintaining the survey's internal reliability. Dependent-samples t-tests were conducted to compare students' mean data with specific variables. The results of these analyses are found in Table 5. Analysis revealed students' mean post-instruction BEL Survey index scores (M = 71.72, SD = 8.80) were significantly higher ($p < .01$) than their mean pre-instruction survey scores (M = 70.11, SD = 6.97). In addition, a significant difference between the mean number of students' pre-instruction BEL Survey "undecided/never heard of it" responses and the mean number of post-instruction "undecided/never heard of it" responses was discovered coupled with significant differences in the mean number of pre- and post-instruction "strongly agree" responses and "strongly disagree" responses. There were no significant differences produced between the mean number of "somewhat agree" or "somewhat disagree" responses, pre- versus post-instruction.

The number of misconceptions held by students on the pre-instruction survey totaled 4812, producing a mean misconception rate per student of 8.98 (SD = 2.75) whereas the number of misconceptions held by students following instruction increased to a total of 5072 with an accompanying student mean increase of 0.48 to 9.46 (SD = 2.59). Analyses revealed the mean number of student pre-instruction misconceptions was significantly lower than the mean number of student post-instruction misconceptions. Of the 536 student participants, 216 decreased in the number of misconceptions from pre- to post-instruction, 259 increased in the number of misconceptions, and for the remaining 61 students the number of misconceptions remained unchanged.

Student Variables

An independent-samples t-test was conducted to evaluate the null hypothesis stating there was no significant difference between the mean difference in the number of pre- and post-instruction misconceptions for male versus female students (see Table 6). Although the t-test result was not significant, female students in the study did possess a higher mean difference between pre- and post-instruction number of misconceptions (M = +0.60, SD = 3.39) as compared to males (M = +0.35, SD = 3.36).

One-way analyses of variance (ANOVA) were performed to evaluate the relationship between the mean difference in number of students' pre- and post-instruction misconceptions and various student variables. The ANOVA results can be found in Table 7. ANOVA conducted to evaluate the relationship between the mean difference in number of pre- and post-instruction misconceptions when compared to student ethnicities, grade level, and pre- and post-instruction ratings of biological evolution knowledge proved to be nonsignificant. In addition, two variables associated with students' public high schools were evaluated with ANOVA in order to determine the variables' relationships to the mean difference in number of students' pre- and post-instruction misconceptions. For both the independent variables of urban-centric location and ADM, the ANOVA results were nonsignificant (see Table 7).

A dependent-samples t-test was subsequently conducted to evaluate whether there existed a significant difference between students' mean pre-instruction self-rating of biological evolution knowledge and their mean post-instruction self-rating (see Table 5). For analysis, the self-rating classes were numerically scaled as follows: (a) poor, 5; (b) fair, 4; (c) average, 3; (d) good, 2; and (e) excellent, 1. Results indicate that students' mean post-instruction self-rating score of biological evolution knowledge (M = 2.77, SD = 0.90) was significantly lower ($p < .01$) than their mean pre-instruction self-rating score (M = 3.30, SD = 0.99), indicating that students presumed themselves to be more knowledgeable about biological evolutionary concepts following instruction than prior to instruction.

Teacher Variables

An independent-samples *t*-test was conducted to evaluate changes in the mean difference in the number of students' pre- and post-instruction misconceptions based on the gender of the students' teachers (see Table 6). Although students of male teachers ($n = 278$) did have a 232.8% increase in the mean difference in the number of pre- and post-instruction misconceptions ($M = 0.73$, $SD = 3.41$) over that of students of female teachers ($n = 258$, $M = 0.22$, $SD = 3.33$), analysis indicated that teachers' gender did not produce a statistically significant difference in the mean difference in number of student's pre- and post-instruction misconceptions ($p = .08$).

ANOVA was employed to evaluate the relationship between the mean difference in the number of students' pre- and post-instruction misconceptions and teacher variables. The results of these analyses are located in Table 7. Teachers' terminal degree included three levels: (a) bachelor's, (b) master's, and (c) doctorate. The ANOVA relating the mean difference in the number of students' pre- and post-instruction misconceptions and teachers' terminal degrees was significant ($p < .01$). Because the overall *F* test was significant, follow-up tests were conducted to evaluate pairwise differences among the means. Because there may have been a lack of power associated with the test due to the small sample size of students of teachers possessing doctorate degrees ($n = 43$), the results of the Dunnett's T3 test, a multiple comparison procedure that does not require the population variance to be equal, was implemented. A significant difference ($p < .01$) in the means between those students whose teachers possessed a bachelor's degree ($M = 0.27$, $SD = 3.36$) and those students whose teachers possessed doctorate degrees ($M = 2.21$, $SD = 3.39$) was revealed as was a significant difference (*p* = .01) between the means of students whose teachers possessed master's degrees (*M* = 0.45, *SD* = 3.28) and those students whose teachers possessed doctorates. An ANOVA was also conducted to evaluate the relationship between the mean difference in the numbers of students' pre- and post-instruction misconceptions and teachers' bachelor's degree major. The independent variable, the teachers' bachelor's degree major, included four classes: (a) nonscience degree, (b) science education degree, (c) nonbiology science degree, and (d) biology degree. Because the overall *F* test was significant (*p* < .05), follow-up tests were conducted to evaluate pairwise differences among the means. Because the variances among the four groups ranged from 9.21 to 13.79, it was not assumed that the variances were homogeneous and a post hoc comparison was conducted with the use of Dunnett's T3 test. A significant difference (*p* < .05) was discovered in the mean difference in the numbers of students' pre- and post-instruction misconceptions between students' whose teachers held nonscience bachelor degrees (*M* = 1.50, *SD* = 3.71) and those students whose teachers held science education bachelor degrees (*M* = .08, *SD* = 3.04). A significant difference (*p* < .05) also was revealed in the means between students whose teachers held nonscience bachelor degrees and those students whose teachers held nonbiology science degrees (*M* = .57, *SD* = 3.34).

ANOVA were conducted to evaluate the relationship between the mean difference in the number of students' pre- and post-instruction misconceptions and their teachers' years of teaching experience, ratings of emphasis placed on biological evolution in their college course, and knowledge rating of evolution. None of the ANOVA results for these three variables proved to be significant (see Table 7). Finally, ANOVA was conducted to evaluate the relationship between the mean difference in the number of students' pre- and post-instruction misconceptions and the number of hours their teachers dedicated to teaching evolution in the Biology I course. The independent variable, hours spent teaching evolution, included five levels: (a) 0, (b) 1 to 5, (c) 6 to 10, (d) 11 to 15, and (e) greater than 15 hours. The ANOVA proved to be significant, ($p < .01$; see Table 7). Because the overall F test was significant, follow-up tests were conducted to evaluate pairwise differences among the means. Because the variances among the five groups ranged from 8.87 to 14.03 it was not assumed that the variances were homogeneous and because there may have been a lack of power associated with the test due to the small sample size of students of teachers dedicating 0 hours ($n = 17$) and those dedicating 11-15 hours ($n = 45$), the Dunnett's T3 test was utilized. A significant difference ($p < .05$) in the means between those students whose teachers dedicated 0 hours to the teaching of biological evolution ($M = -1.0$, $SD = 2.98$) and those students whose teachers dedicated 11 to 15 hours to the topic ($M = 2.0$, $SD = 3.49$) was revealed as was a significant difference between the means of students whose teachers dedicated 6 to 10 hours ($M = .01$, $SD = 3.28$) and those who dedicated 11 – 15 hours to the teaching of evolution.

BEL Survey Statement Analysis

The 35 teachers' BEL Survey index scores were ranked from highest to lowest and divided into two groups. The group containing the 18 highest ranking teacher index scores ($M = 103.11$, $SD = 5.72$) was designated the High Index Score Group (HISG) whereas the group containing the 17 lowest ranking index scores ($M = 79.64$, $SD = 9.74$) was designated the Low Index Score Group (LISG). Independent *t*-test analysis revealed significant differences between both the mean change in students' pre- and post-instruction BEL Survey index scores ($p < .01$) and the mean change in the number of students' pre- and post-instruction biological evolution misconceptions ($p < .05$) when student data from the HISG and LISG teacher groups were compared (see Table 8). Those students of teachers in the HISG ($n = 290$) had a mean increase of 2.58 index points ($SD = 9.25$) from pre- to post-instruction whereas those students of teachers in the LISG ($n = 246$) had a mean increase of only 0.47 index points ($SD = 8.40$). Similarly, students of HISG teachers had a mean increase of 0.20 misconceptions ($SD = 3.48$) from pre- to post-instruction whereas students of the LISG teachers had a mean increase of 0.82 misconceptions ($SD = 3.23$).

To determine the relationship between teachers' biological evolution misconceptions and their students' acquisition of the same misconceptions, from pre- to post-instruction, each teacher's responses to the BEL Survey's 23 statements were analyzed to determine which specific misconceptions they did and did not possess. Students' collective mean change in the number of each specific statement misconception, from pre-instruction to post-instruction, was calculated for students whose teachers held the specific statement misconception and for students whose teachers lacked the statement misconception, i.e., possessed the accurate concept. Only students whose teachers possessed either the statement's misconception or accurate concept were entered into analysis. Students of teachers who selected "undecided/never heard of it" as a response or who did not have an opinion concerning the statement were not entered into the analysis. Results of the independent *t*-test analysis are revealed in Table 9.

For both statements 1 ("A scientific theory that explains a natural phenomenon can be defined as a 'best guess' or 'hunch'") and 20 ("There exists a large amount of evidence supporting the theory of evolution"), significant differences ($p < .05$) were discovered between the mean change in the number of misconceptions held by students whose teachers possessed the statement misconception compared to the mean change in the number of misconceptions held by students whose teachers possessed the accurate statement concept. Students whose teachers possessed the misconception associated with statement 1 had a statistically significant ($p < .05$) -0.19 decrease in the mean number of misconceptions from pre- to post-instruction as compared to a -0.01 decrease in the mean number of misconceptions for students whose teachers possessed the accurate biological evolution concept for the statement. However, students whose teachers possessed the statement 20 misconception had a 0.22 increase in the mean number of misconceptions from pre- to post-instruction as compared to a -0.01 mean decrease for students whose teachers possessed the accurate biological evolution concept, producing a significant difference between the two of $p < .01$.

Analysis revealed there to be ten BEL Survey statements (2, 3, 5, 14, 16, 17, 18, 20, 22, and 23) in which the mean change in the number of misconceptions held by students whose teachers accepted the statement misconception were greater than the mean change in the number of misconceptions held by students of teachers who rejected the statement misconception, producing a mean $p = .36$ (see Table 9). There were likewise ten statements (1, 4, 6, 7, 8, 9, 11, 13, 15, 21) in which the mean change in the number of misconceptions held by students whose teachers possessed the statement misconception were less than the mean change in the number of misconceptions held by students whose teachers lacked the statement misconception, producing a mean $p = .31$ (see Table 9). No mean changes in the number of misconceptions between the two groups of students were produced by statements 10 and 12. One statement, number 19, was not analyzed because the statement misconception was not possessed by any of the teachers.

To assess the degree to which the numbers of teachers' misconceptions are linearly related to students' post-instruction BEL Survey index scores, Pearson product-moment correlation coefficient (r) was employed. Analysis revealed the correlation between teachers' number of misconceptions and students' post-instruction BEL Survey index scores was significant, $r(534) = -.17$, $p < .01$. In general, the results suggest a small inverse correlation between the two variables, indicating that as the number of teachers' misconceptions increase, students' post-instruction BEL Survey mean index scores decrease and, as the number of teachers' misconceptions decrease, students' post-instruction mean index scores increase. However, r^2 indicates that only 2.9% of students' index scores are predicted by the number of teachers' misconceptions.

Discussion

Comparison of Students' Pre- and Post-instruction BEL Survey Results

At first glance, the fact that students had a statistically significant increase ($p < .05$) in BEL Survey index scores from the pre-instruction survey ($M = 70.11$, $SD = 6.97$) to the post-instruction survey ($M = 71.72$, $SD = 8.80$) seems to indicate that students possessed fewer biological evolution misconceptions following instruction as opposed to prior to instruction – a result to be expected if students' misconceptions were supplanted by accurate concepts during the teaching process. On closer examination, however, such was not the case as the total number of students' misconceptions increased by 260 following instruction, from 4812 pre-instruction misconceptions to 5072 post-instruction misconceptions. The discrepancy between the positive change in student mean index scores and the increase in mean number of misconceptions from pre- to post-instruction can primarily be accounted for by a statistically significant reduction in the mean number of "undecided/never heard of it" responses from pre- to post-instruction (3.92 to 2.15) coupled with statistically significant increases in the mean number of pre- and post-instruction "strongly agree" responses (4.20 to 4.88) and "strongly disagree" responses (4.05 to 4.80; see Table 5). While a slight majority of those students who selected pre-instruction "undecided/never heard of it" response subsequently selected the accurate post-instruction statement concepts, thus elevating the BEL Survey mean index score, a slightly smaller number selected the statements' misconceptions which resulted in an increase in the total number of misconceptions from pre- to post-instruction.

While students were obviously more confident in their responses following instruction, this new-found confidence was inversely correlated to their competency in the subject matter. This finding replicates similar results identified by multiple researchers (e.g., Bishop & Anderson, 1990; Cunningham & Wescott, 2009; Wilson, 2001). This increase in confidence was predominately a female phenomenon as the average change in "undecided/never heard of it" responses decreased from pre- to post-instruction BEL Survey by 0.74 per female student (n = 287) while decreasing only 0.38 per male student (n = 249). This outcome may be because females were more indecisive in their initial pre-instruction survey statement responses than were males, with females producing a mean 4.25 (n = 287, SD = 4.01) "undecided/never heard of it" response rate for the 23 BEL Survey statements as opposed to males' mean 3.54 (n = 249, SD = 3.61) response rate, producing a significant difference between the two of $t(534) = 2.14$, $p < .05$. Such a phenomenon was likewise documented in both Almquist and Cronin's (1988) and Cunningham and Wescott's (2009) studies.

Additional evidence indicating an increase in student confidence in their knowledge of biological evolution following instruction was found in the comparison of students' biological evolution knowledge self-rating scoring means, prior to and following instruction. Here, students rated themselves to be more knowledgeable about biological evolution following instruction as opposed to prior to instruction. Again, however, the confidence gained, evidenced by an improvement in students' mean knowledge self-rating from pre- to post-instruction, did not correlate to increased competency in subject matter.

Researchers have observed that students are able to recognize the scientifically acceptable answer when a statement is phrased correctly, such as BEL Survey statement 2, for example. However, when a statement is put forth that includes a common misconception, such as BEL Survey statement 1, students tend to agree with the misconception (Almquist & Cronin, 1988; Cunningham & Wescott, 2009). The present study did find a similar trend in students' responses with correctly phrased statements (n = 10) accounting for a mean post-instruction student misconception rate of 198.30 (SD = 52.10) out of a possible 536 student responses while statements that included a common misconception (n = 13) produced a mean student misconception rate of 237.62 (SD = 84.93). To Cunningham and Wescott (2009) such a trend suggested that,

" . . . while our students may have heard the scientifically accurate definition of terms such as theory, fitness, and natural selection, they do not truly understand them" (p. 514). This researcher strongly concurs.

Student variables

Previous studies have shown that student misconceptions about science can differ significantly based on multiple variables including geographical region, religious background, generation, gender, and age (Almquist & Cronin, 1988; Losh, Travani, Njoroge, Wilke, & Mcauley, 2003; Morrison & Lederman, 2003; Palmer, 1999). This study found no significant difference between the mean difference in the number of students' pre- and post-instruction biological evolution misconceptions when related to students' gender, ethnicity, grade level, biological evolution knowledge self-rating, or students' public high schools' urban-centric locations or ADM. With these variables minimized as contributing factors to student acquisition of biological evolution misconceptions, the focus then turns to the role of the teacher.

Teacher variables

Even though the difference proved to be outside the realm of significant ($p = .08$), it is interesting to note that students of male teachers had a 232.8% increase in the mean difference in the number of misconceptions from pre- to post-instruction over that of students of female teachers. This result could simply have occurred because female teachers in this study ($n = 17$) appeared to be more knowledgeable of biological evolution as indicated by their mean 94.40 BEL Survey index score ($SD = 13.69$) and 4.29 mean misconception rate ($SD = 3.87$) for the 23 survey statements as compared to the male teachers' 89.2 mean index score ($n = 18$, $SD = 14.6$) and 5.83 mean misconception rate (*SD* = 3.78). This explanation appears to be valid based on the results obtained when teachers' index scores were ranked regardless of gender, divided into either a high index scoring group (*n* = 18, *M* = 103.11, *SD* = 5.72) or a low index scoring group (*n* = 17, *M* = 79.64, *SD* = 9.74), and then compared to the mean difference in both students' pre- and post-instruction index scores and number of misconceptions. Students whose teachers' index scores fell in the HISG generated a mean index score increase of 2.58 (*n* = 290, *SD* = 9.25) from pre- to post-instruction and a 0.20 mean increase in number of misconceptions (*SD* = 3.48) while those students whose teachers' index scores were in the LISG produced a mean index score increase of only 0.47 (*n* = 246, *SD* = 8.40) coupled with a 0.82 mean increase (*SD* = 3.23) in number of misconceptions. Thus, while teachers' gender may play a role in students' acquisition of biological evolution-related misconceptions, a more important factor appears to be the biological evolution knowledge possessed by the teachers themselves. Certainly additional research is warranted in this area.

Whereas significant differences ($p < .05$) were discovered in the mean difference in number of students' pre- and post-instruction misconceptions between students whose teachers possessed either bachelor's or master's degrees and students whose teachers possessed doctorate degrees, one must proceed with caution. Only 43 of the 536 student participants were students of teachers possessing doctorate degrees (*n* = 3), representing only 8.0% of the student population while 169 were students of teachers possessing terminal master's degrees (*n* = 10, 31.5%), and 324 were students of teachers possessing terminal bachelor's degrees (*n* = 22, 60.5%). No doubt, larger sample sizes of teachers possessing doctorates along with their students are required to verify the results of this study. It is interesting to note, however, those students ($n = 324$) of teachers possessing terminal bachelor's degrees had a mean increase of 0.27 ($SD = 3.36$) misconceptions following instruction as compared to a mean increase of 0.45 ($SD = 3.28$) for those students ($n = 169$) of teachers possessing terminal master's degrees. Results of this study indicate that such a difference in students' mean number of misconceptions from pre- to post-instruction may be more closely tied to the teacher's bachelor's degree field than to terminal degree level as previous research has revealed that teachers' understanding of content is nearly directly correlated with their education (Hoy, Davis, & Pape, 2006; Pajares, 1992). Students of teachers possessing science education, nonbiology science, and biology bachelor's degrees had mean misconception increases from pre- to post-instruction of 0.08 ($n = 125$, $SD = 3.04$), 0.11 ($n = 122$, $SD = 3.46$), and 0.57 ($n = 195$, $SD = 3.34$) respectively, while students of teachers possessing nonscience bachelor's degrees had a mean pre- to post-instruction increase of 1.50 ($n = 180$, $SD = 3.71$) misconceptions. Significant differences ($p < .05$) revealed between the mean difference in students' numbers of pre- and post-instruction misconceptions between students of teachers possessing either science education or nonbiology science bachelor's degrees and students of teachers possessing nonscience bachelor's degrees indicate that students' numbers of biological evolution-related misconceptions are more likely to increase from pre- to post-instruction if they are taught by teachers lacking science-related bachelor's degrees. Approximately 54.5% ($n = 12$) of those teachers with terminal bachelor's degrees ($n = 22$) held either a science education or nonbiology science degree compared to only 30.0% ($n = 3$) of those teachers possessing terminal master's degrees ($n = 10$), and 0.0% of those teachers holding doctorate degrees (*n* = 3), while their students produced mean pre- to post-instruction misconception number increases of 0.27 (*SD* = 3.36), 0.45 (*SD* = 3.28), and 2.21 (*SD* = 3.39) respectively.

No significant differences were discovered in the mean difference between students' numbers of pre- and post-instruction misconceptions when related to their teachers' years of teaching experience, teachers' rating of emphasis placed on biological evolution in their college courses, or teachers' self-rating of biological evolution knowledge. However, statistically significant differences in the mean difference between students' numbers of pre- and post-instruction misconceptions were revealed related to the number of hours teachers dedicate to teaching biological evolution concepts in the Biology I course with 6 to 10 hours of teacher instruction identified as the optimum duration. Although 6 to 10 hours of evolution instruction does not appear to reduce the number of misconceptions students bring into the classroom, this duration does seem to inhibit their development as opposed to shorter or longer durations of instruction where the number of students' misconceptions increased from their initial levels by levels higher than the 0.01 mean increase afforded by the 6 to 10 hours of instruction. Interestingly, one teacher in the study indicated dedicating no hours to the teaching of evolution in the Biology I course yet produced the most favorable student results. This teacher's students (*n* = 17) had a mean decrease of 1.0 (*SD* = 2.98) misconceptions from pre- to post BEL Survey while presumably lacking any teacher instruction. Of course, time spent in accurate, quality evolution instruction is no doubt more important than the quantity of time a teacher spends teaching evolutionary concepts in the classroom.

BEL Survey Statement Analysis

Especially enlightening were those results obtained when the 35 teachers' BEL Survey index scores were ranked from highest to lowest, subsequently divided into two groups--the HISG and the LISG--and, the mean change in both groups' students' BEL Survey index scores and number of misconceptions from pre- to post-instruction were analyzed. Results revealed that from pre- to post-instruction, those students of teachers classified in the HISG produced a significantly higher ($p < .01$) mean index score coupled with a significantly lower ($p < .05$) mean number of misconceptions than did those students whose teachers were classified in the LISG (keeping in mind that the mean number of misconceptions increased for both groups of students from pre- to post-instruction). These results indicate that students of teachers who possess a relatively better knowledge of biological evolution have an increased opportunity to learn and retain biological evolution-related concepts and--while the data do not indicate a concurrent reduction in evolution misconceptions--at least an opportunity to minimize the number of new misconceptions acquired during the course of instruction as opposed to those students taught by teachers with a relatively poorer knowledge of biological evolution concepts. Studies repeatedly show the positive impact effective teachers can have on student achievement. For example, both Sanders and Horn (1994) and Marzano (2003) revealed a 39.0 percentage point difference in student achievement gains between students with *most effective* and *least effective* teachers (as cited in Miller, 2003, p. 2).

When each of the 23 BEL Survey statements was independently analyzed to determine which teachers possessed the associated misconception and which did not, followed by analysis of the mean change in their students' numbers of misconceptions from pre-instruction to post-instruction, the data revealed conflicting results (see Table 9). Analysis revealed 10 BEL Survey statements in which the mean positive change in the number of misconceptions held by students whose teachers adhered to the statement misconception were greater than the mean positive change in the number of misconceptions held by students of teachers who did not possess the statement misconception. There were likewise 10 survey statements in which the mean positive change in the number of misconceptions held by students whose teachers possessed the statement misconceptions were less than the mean positive change in the number of misconceptions held by students of teachers who lacked the misconception. Only one of the 10 survey statements which were revealed as possible contenders for the transmission of the statement misconception from teacher to student did so at a statistically significant level. This statement, number 20, ("There exists a large amount of evidence supporting the theory of evolution"), produced a 0.22 (SD = 0.59) increase in the mean number of misconceptions from pre- to post-instruction in those students whose teachers possessed the misconception as opposed to a 0.01 (SD = 0.59) decrease in students whose teachers lacked the misconception. At the p = .0001 level of significance, there exists a high probability that this particular misconception was passed from teacher to student. Were other misconceptions passed from teacher to student? Most likely, as several other BEL Survey statements teetered on the brink of statistical significance (see Table 9) but only statement 20 crossed the line at the $p < .05$ level of significance.

Even though analysis identified only one BEL Survey statement misconception to be transmitted from teachers to their students, the study did reveal an important relationship between teachers' levels of misconceptions and student achievement which may provide additional evidence of misconception transmission from teachers to students. Results suggest an inversely correlated relationship between the number of teachers' misconceptions and students' post index scores, i.e., as the number of teachers' misconceptions increased, students' post-index scores decreased and, as the number of teachers' misconceptions decreased, students' index scores increased. Transmission of misconceptions from these teachers to their students cannot be ruled out as a causative agent although several variables may come into play in the decrease of students' index scores following instruction by teachers with high levels of misconceptions,

Limitations of Study

Several possible limitations were evident in this study. For example, all teacher participants volunteered for the study and therefore are probably not a truly random sample of all Oklahoma public high school Biology I teachers. Similarly, during the duration of the study some students may have been exposed to biological evolution misconceptions in non-biology courses or in other contexts. In addition, for some variables tested, small teacher and/or student sample sizes may have produced results that were not representative of the population as a whole. In light of these limitations, a completely causative link between students' acquisition of biological evolution misconceptions and the variables defined within the study is not assigned. Nevertheless, evidence suggests that the data reported here are reliable and representative, and the results are consistent with those reported by previous researchers (e.g., Almquist & Cronin, 1988; Bishop & Anderson, 1990; Cunningham & Wescott, 2009; Wilson, 2001).

Conclusion

This study revealed some problematic issues concerning the teaching of biological evolution in Oklahoma's public high school introductory biology course, as evidenced by the fact that the average student in the study completed the Biology I course with increased confidence in their biological evolution knowledge yet with a greater number of biological evolution misconceptions and, therefore, less competency in the subject. Who's culpable? Certainly one's first compulsion is to implicate the teacher. Such a verdict may be justified in many cases as research has revealed ". . . instruction in evolutionary biology at the high school level has been absent, cursory, or fraught with misinformation" (Rutledge & Mitchell, 2002, p. 21) and ". . . about one-fourth of Oklahoma public school life-science teachers place moderate or strong emphasis on creationism" (Weld & McNew, 1999, pg. 52). Disturbingly, this study revealed two cases in which students who entered their Biology I courses held a higher pre-instruction BEL Survey mean index score than the index scores produced by their respective teachers on the same survey. This result indicates that these students, on average, had a more accurate understanding of biological evolution prior to instruction than did their teachers whose task was to instruct them in the topic. Based on this result alone, there is little doubt that teachers may serve as sources of biological evolution-related misconceptions or, at the very least, propagators of existing misconceptions.

Identifying the sources of misconceptions is difficult at best. While this study focused primarily on teachers as a source of student biological evolution misconceptions, other contributing factors may certainly have played a role, including religious and parental influences, textbooks, and popular media, all of which have been known to foster student misconceptions (e.g., Cavallo & McCall, 2008; Linhart, 1997) as well as content and teachers associated with other courses. Evidence exists as well implicating the topic of evolution as being too complex for high school students, most of whom still think at the concrete level, lacking the cognitive development necessary to comprehend biological evolution-related concepts fully and are therefore unable to construct solid accurate understandings of the topic (Lawson & Thompson, 1988; Settlage, 1994). No doubt, multiple factors contribute in varying degrees to the acquisition and retention of student misconceptions of biological evolution. It is imperative, then, that we as educators identify sources of student biological evolution-related misconceptions, identify or develop strategies to reduce or eliminate such misconceptions, and then implement these strategies at the appropriate junctures in students' cognitive development. If teachers are unaware of the misconceptions prevalent with students and do not take them into consideration when implementing instructional strategies, they may hold overly optimistic expectations of the effectiveness of their teaching (Lightman & Sadler, 1993).

The Oklahoma Academy of Science strongly supports thorough teaching of evolution in biology classes, deeming evolution one of the most important principles of science while noting that "a high school graduate who does not understand evolution is not prepared for college or for life in a technologically advanced world in which the role of biology and biotechnology will continue to grow" (2007, p. 1) These graduates deserve a high school biology teacher who functions not as a source of students' misconceptions but rather as a resource for their identification and elimination. Yet, students' knowledge structures have been found to approximate those of their teachers (Rutledge & Mitchell, 2002), and currently substantial numbers of biology students become biology teachers while still retaining major misconceptions (Nehm, Poole, Lyford, Hoskins, Carruth, Ewers et al., 2008). We must work diligently to disrupt this cycle.

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Table 1

Teacher Profile

Demographic Variable	Variables	*n*	%*
Gender	Female	17	48.6
	Male	18	51.4
Terminal degree	Bachelor's	22	62.9
	Master's	10	28.6
	Doctorate	3	8.6
Bachelor's degree major	Biology	13	37.1
	Nonbiology science	8	22.9
	Science education	7	20.0
	Nonscience	6	17.1
	No response	1	2.9
Years teaching experience	0 – 5	7	20.0
	6 – 10	4	11.4
	11 – 15	6	17.1
	16 – 20	7	20.0
	> 20	11	31.4

Table 1 (continued).

Demographic Variable	Variables	*n*	%*
College education evolution emphasis	Highly emphasized	3	8.6
	Moderately emphasized	14	40.0
	Slightly emphasized	12	34.3
	Not emphasized	5	14.3
	No response	1	2.9
Hours dedicated to teaching evolution	0	1	2.9
	1-5	17	48.6
	6-10	7	20.0
	11-15	3	8.6
	>15	7	20.0
Evolution knowledge self-rating	Excellent	7	20.0
	Good	17	48.6
	Average	7	20.0
	Fair	4	11.4
	Poor	0	0.0

*Percentages may not total 100 due to rounding

Table 2

Student Profile

Demographic Variable	Variables	*n*	%*
Gender	Female	287	53.5
	Male	249	46.5
Ethnicity	American Indian or Alaskan Native	76	14.2
	Asian or Pacific Islander	9	1.7
	Black, non-Hispanic	19	3.5
	Hispanic	34	6.3
	White, non-Hispanic	390	72.8
	No response	8	1.5
Grade level	Freshman	131	24.4
	Sophomore	394	73.5
	Junior	8	1.5
	Senior	1	0.2
	No response	2	0.4

Table 2 (continued).

Demographic Variable	Variables	*n*	%*
Evolution knowledge self-rating (Pre)	Excellent	18	3.4
	Good	76	14.2
	Average	242	45.1
	Fair	120	22.4
	Poor	76	14.2
	No response	4	0.7
Evolution knowledge self-rating (Post)	Excellent	36	6.7
	Good	158	29.5
	Average	254	47.4
	Fair	63	11.8
	Poor	23	4.3
	No response	2	0.4

Note. *Pre* = pre-instruction; *Post* = post-instruction

*Percentages may not total 100 due to rounding.

Table 3

BEL Survey Statement Teachers' and Students' Percent Responses

#	Category	Statement	% Response* 1	2	3	4	5	6
1	SSMT1	A scientific theory that explains a natural phenomenon can be classified as a "best guess" or "hunch."[a]	2.9	11.4	8.6	77.1	0.0	0.0
			11.9	37.3	22.9	11.9	15.7	0.2
			14.0	31.9	22.2	22.0	9.5	0.4
2	SSMT2	The scientific methods used to determine the age of fossils and the earth are reliable.	42.9	28.6	20.0	8.6	0.0	0.0
			22.6	50.4	14.0	6.3	6.5	0.2
			25.0	44.0	16.4	9.9	4.7	0.0
3	SSMT3	According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms.	11.4	11.4	20.0	28.6	25.7	2.9
			9.5	11.0	16.8	17.2	44.8	0.7
			10.8	17.7	23.5	21.1	26.3	0.6
4	SSMT4	The earth is old enough for evolution to have occurred.	54.3	22.9	5.7	11.4	5.7	0.0
			28.5	27.4	11.9	20.0	11.6	0.6
			36.4	23.3	12.7	18.8	7.8	0.9

Table 3 (continued).

#	Category	Statement	% Response*					
			1	2	3	4	5	6
5	SSMT5	Evolution cannot be considered a reliable explanation because evolution is only a theory.	5.7	17.1	11.4	60.0	2.9	2.9
			30.2	24.8	20.5	13.4	10.8	0.2
			30.8	27.1	19.6	16.0	6.3	0.2
6	IE1	Evolution always results in improvement. [a]	5.7	11.4	25.7	54.3	2.9	0.0
			6.9	22.8	28.2	25.4	14.9	1.9
			7.5	22.4	30.8	29.3	8.6	1.5
7	IE2	Members of a species evolve because of an inner need to evolve.[a]	2.9	8.6	11.4	71.4	5.7	0.0
			11.2	28.9	21.1	16.4	22.4	0.0
			9.5	26.1	24.4	23.9	15.5	0.6
8	IE3	Traits acquired during the lifetime of an organism-such as large muscles produced by body building-will not be passed along to offspring.	77.1	8.6	8.6	5.7	0.0	0.0
			30.0	24.6	19.0	17.5	8.8	0.0
			42.0	21.3	16.6	13.8	6.0	0.4

Table 3 (continued).

#	Category	Statement	% Response*					
			1	2	3	4	5	6
9	IE4	If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation. [a]	17.1	22.9	0.0	60.0	0.0	0.0
			9.1	1.9	21.8	11.6	24.6	0.9
			18.3	35.8	23.1	11.2	10.6	0.9
10	IE5	Evolution cannot cause an organism's traits to change within its lifetime.	71.4	11.4	5.7	8.6	2.9	0.0
			16.6	20.1	26.5	15.9	19.6	1.3
			20.1	29.9	20.7	18.5	9.9	0.9
11	NE1	New traits within a population appear at random.[b]	48.6	25.7	14.3	8.6	2.9	0.0
			10.3	30.6	26.9	13.8	17.9	0.6
			9.9	28.5	31.0	22.2	8.0	0.4
12	NE2	Individual organisms adapt to their environments.	20.0	22.9	11.4	45.7	0.0	0.0
			49.4	32.1	8.2	4.1	5.2	0.9
			44.2	32.8	11.4	7.8	3.0	0.7

Table 3 (continued).

#	Category	Statement	% Response*					
			1	2	3	4	5	6
13	NE3	Evolution is a totally random process.	22.9	20.0	20.0	34.3	2.9	0.0
			10.1	16.0	24.4	25.4	23.7	0.4
			11.6	19.0	26.3	30.0	12.5	0.6
14	NE4	The environment determines which traits are best suited for survival.	51.4	37.1	11.4	0.0	0.0	0.0
			24.3	33.6	17.2	11.9	12.3	0.7
			31.3	34.0	20.7	8.8	5.0	0.2
15	ME1	Variation among individuals within a species is important for evolution to occur. [a]	74.3	17.1	8.6	0.0	0.0	0.0
			11.2	28.0	18.8	9.3	32.6	0.0
			21.5	34.3	19.0	12.1	12.5	0.6
16	ME2	"Survival of the fittest" means basically that "only the strong survive."[b]	8.6	31.4	17.1	42.9	0.0	0.0
			35.8	27.2	17.2	12.5	7.1	0.2
			44.8	24.4	13.6	12.7	4.5	0.0

Table 3 (continued).

#	Category	Statement	% Response*					
			1	2	3	4	5	6
17	ME3	The size of the population has no effect on the evolution of a species. [a]	2.9	0.0	31.4	65.7	0.0	0.0
			12.5	17.4	33.2	21.8	14.9	0.2
			12.7	21.6	27.6	29.7	7.8	0.6
18	ME4	Complex structures such as the eye could have been formed by evolution.	34.3	17.1	11.4	34.3	2.9	0.0
			10.8	26.1	17.4	25.9	19.2	0.6
			15.5	22.4	21.1	29.9	10.6	0.6
19	ME5	Only beneficial traits are passed on from parent to offspring.	0.0	0.0	17.1	82.9	0.0	0.0
			8.8	21.5	26.5	34.0	8.2	1.1
			7.8	23.9	21.8	40.1	6.0	0.4
20	ESE1	There exists a large amount of evidence supporting the theory of evolution. [a]	51.4	11.4	11.4	22.9	2.9	0.0
			14.0	22.2	19.2	23.9	20.3	0.4
			14.6	28.4	21.8	26.5	8.6	0.2

Table 3 (continued).

#	Category	Statement	% Response*					
			1	2	3	4	5	6
21	ESE2	According to the theory of evolution, humans evolved from monkeys, gorillas, or apes.	17.1	14.3	1.4	54.3	2.9	0.0
			25.9	25.0	10.6	30.2	8.2	0.0
			23.9	23.5	12.1	34.1	6.3	0.0
22	ESE3	Scientific evidence indicates that dinosaurs and humans lived at the same time in the past. [a]	8.6	14.3	5.7	62.9	8.6	0.0
			13.6	20.7	17.7	28.2	19.0	0.7
			12.7	20.5	21.6	32.5	12.3	0.4
23	ESE4	The majority of scientists favor evolution over other explanations for life.	42.9	34.3	17.1	5.7	0.0	0.0
			16.4	28.4	21.8	10.6	22.2	0.6
			20.0	34.7	20.5	12.1	12.3	0.4

Note. Percent response is identified as follows: first row, teacher participants ($N = 35$); second row, pre-instruction student participants ($N = 536$); third row, post-instruction student participants (N = 536). *SSMT* = science, scientific methodology and terminology; *IE* = intentionality of evolution; *NE* = nature of evolution; *ME* = mechanisms of evolution; *ESE* = evidence supporting evolution; *1* = strongly agree; *2* = somewhat agree; *3* = somewhat disagree; *4* = strongly disagree; *5* = undecided/never heard of it; *6* = no response. Shaded areas indicate percentage of participants accepting the statement-related misconception.

*Percentages may not total 100 due to rounding.

[a]Statement adapted from Cunningham and Wescott (2009).

[b]Statement taken directly from Cunningham and Wescott (2009).

Table 4

Public High School Profile

Demographic variable	Variable range	Percentage of High schools	
		Participant HS (*N* = 32)	Study area HS (*N* = 474)
Average daily membership[a]	4451.85 – 485.57	25.0	20.0
	482.10 – 242.95	25.0	20.0
	242.30 – 134.10	21.9	20.0
	132.10 – 78.11	9.4	20.0
	77.73 – 14.85	18.8	20.0
Urban-centric classification[b]*	City	3.1	7.2
	Suburban	6.3	5.7
	Town	31.2	17.7
	Rural	59.4	69.4

Note. *HS* = high school. Participant high schools contain study participants whereas study area high schools are the total number of high schools within the study area. Percentages may not equal 100% due to rounding.

[a]Average daily membership (ADM) is the aggregate membership of a school during a reporting period (normally a school year) divided by the number of days school is in session during this period (IESNCES, 2010a).

[b]Urban-centric classification (IESNCES, 2010b)

*Difference is statistically significant at $p < .05$.

Table 5

Summary of Analyses of Dependent-samples t-Test Results for Students' Mean Data Related to Specific Variables.

Variable	*Test*	*df*	*M*	*sd*	*t*	*p (2-tailed)*
BEL Survey mean index score	Pre	535	70.11	6.97	4.19	<.01*
	Post		71.72	8.80		
Number of misconceptions	Pre	535	8.98	2.75	3.33	<.01*
	Post		9.46	2.59		
Student self-knowledge rating	Pre	530	3.30	0.99	10.97	<.01*
	Post		2.77	0.90		
Student BEL Survey responses:						
Strongly agree	Pre	535	4.20	2.87	4.82	<.01*
	Post		4.88	3.04		
Somewhat agree	Pre	535	6.07	2.84	1.39	.17
	Post		6.28	3.09		
Strongly disagree	Pre	535	4.05	2.66	5.51	<.01*
	Post		4.80	2.98		
Somewhat disagree	Pre	535	4.62	2.80	1.07	.28
	Post		4.77	2.76		
Undecided/never heard of it	Pre	535	3.92	3.84	10.49	<.01*
	Post		2.15	2.53		

Note. *Pre* = student pre-instruction; *Post-* = student post-instruction.

* Difference between pre- and post-test means is statistically significant at $p \leq .01$.

Table 6

Summary of Independent-samples t-Test Analyses for Students' Mean Difference in Pre- to Post-instruction Mean Number of Misconceptions Related to Gender

	Mean difference in student pre- to post-instruction misconception number				
Variable	*Female*	*Male*	*t*	*df*	*p*
Student gender	+0.60	+0.30	0.84	533	.40
	(3.39)	(3.36)			
Teacher gender	+0.22	+0.73	-1.75	534	.08
	(3.33)	(3.41)			

Note. Standard deviation is located in parentheses below mean difference.

Table 7

Summary of Analyses of Variance Results for Students' Mean Difference in Pre- to Post-instruction Number of Misconceptions Related to School, Student, and Teacher Variables.

Source	*df*	*F*	η	*p*
High School Variables:				
Urban-centric Classification	3	0.72	.07	.54
Average daily membership	4	0.36	.05	.84
Student Variables:				
Grade	3	1.17	.08	.32
Ethnicity	4	0.41	.06	.80
Pre knowledge self-rating	4	1.14	.09	.34
Post knowledge self-rating	4	1.09	.09	.36
Teacher Variables:				
Terminal degree	2	6.38	.15	<.01*
Bachelor's degree major	3	3.58	.15	.01*
Years of teaching experience	4	7.07	.07	.59
College evolution emphasis	3	1.85	.10	.14
Knowledge rating	3	0.73	.06	.53
Hours teaching evolution	4	3.95	.17	<.01*

Note. Analysis was conducted between specified groups of each source.

* Difference between groups is statistically significant at $p \leq .01$

Table 8

Summary of Independent-samples t-Test Analyses for Mean Difference in Pre- to Post-instruction Student Variables Related to Teachers' BEL-MIS Ranking

	Mean difference in student variable pre- to post-instruction				
Student Variable	*Teacher HISG* (n = 290)	*Teacher LISG* (n = 246)	*t*	*df*	*p*
BEL-MIS	+2.58 (9.25)	+0.47 (8.40)	2.75	534	<.01*
Misconception number	+0.20 (3.48)	+0.82 (3.23)	2.11	534	.04**

Note. *BEL-MIS* = BEL Survey mean index score; *HISG* = high index score group; *LISG* = low index score group. Standard deviation is located in parentheses below mean difference.

* Difference between groups is statistically significant at $p < .01$.

** Difference between groups is statistically significant at $p < .05$.

Table 9

Mean Change in Students' Pre- to Post-instruction Misconception Numbers Related to Teachers' With and Without Statement Misconception.

BEL Statement		Student mean misconception number change				
#	Category	Teacher with	Teacher without	*t*	*df*	*p*
1	SSMT1	-0.19 (0.61)	-0.01 (0.65)	2.02	520	0.04*
2	SSMT2	0.08 (0.53)	0.05 (0.52)	0.48	532	0.63
3	SSMT3	0.11 (0.61)	0.07 (0.56)	0.56	398	0.57
4	SSMT4	-0.05 (0.55)	-0.01 (0.58)	0.57	495	0.57
5	SSMT5	0.10 (0.62)	0.01 (0.60)	1.45	502	0.15
6	IE1	-0.09 (0.60)	0.02 (0.59)	1.57	534	0.12
7	IE2	-0.12 (0.64)	-0.04 (0.62)	1.05	516	0.29
8	IE3	-0.11 (0.66)	-0.03 (0.79)	0.85	534	0.39
9	IE4	0.12 (0.71)	0.13 (0.65)	0.15	534	0.88
10	IE5	-0.04 (0.70)	-0.04 (0.63)	0.11	514	0.91
11	NE1	0.06 (0.67)	0.14 (0.64)	1.16	530	0.25
12	NE2	-0.05 (0.46)	-0.05 (0.53)	0.15	534	0.88
13	NE3	0.02 (0.54)	0.08 (0.59)	1.11	511	0.27
14	NE4	0.05 (0.62)	-0.01 (0.59)	0.91	534	0.36

Table 9 (continued).

BEL Survey		Student Mean misconception number change				
#	Category	Teacher with	Teacher without	*t*	*df*	*p*
15	ME1	-0.11	-0.06	1.44	534	0.15
		(0.72)	(0.70)			
16	ME2	0.13	0.05	1.52	534	0.13
		(0.63)	(0.61)			
17	ME3	0.06	0.05	0.05	534	0.96
		(0.66)	(0.58)			
18	ME4	0.14	0.05	1.83	521	0.07
		(0.54)	(0.66)			
19	ME5[a]	-----	-----	-----	-----	-----
20	ESE1	0.22	-0.01	3.96	511	0.0001**
		(0.59)	(0.59)			
21	ESE2	-0.09	-0.01	1.42	521	0.16
		(0.59)	(0.58)			
22	ESE3	0.02	-0.01	0.62	486	0.54
		(0.59)	(0.58)			
23	ESE4	0.05	-0.02	1.12	534	0.26
		(0.59)	(0.59)			

Note. Teacher with = teacher possessing statement misconception; *Teacher without* = teacher lacking statement misconception. Standard deviation is located in parentheses below mean.

[a]Analysis was not conducted as no teacher possessed the statement misconception.

* Difference between groups is statistically significant at $p < .05$.

** Difference between groups is statistically significant at $p < .01$.

APPENDIX A: PROSPECTUS

THE UNIVERSITY OF OKLAHOMA

JEANNINE RAINBOLT COLLEGE OF EDUCATION

STUDENT ACQUISITION OF BIOLOGICAL EVOLUTION-RELATED MISCONCEPTIONS: THE ROLE OF THE SECONDARY SCHOOL LIFE SCIENCE TEACHER

A PROSPECTUS

SUBMITTED TO THE GRADUATE COMMITTEE

In partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

IN

SCIENCE EDUCATION

SUBMITTED BY

TONY B. YATES

Norman, Oklahoma

2010

STUDENT ACQUISITION OF BIOLOGICAL EVOLUTION-RELATED MISCONCEPTIONS: THE ROLE OF THE SECONDARY SCHOOL LIFE SCIENCE TEACHER

A PROSPECTUS APPROVED FOR THE
DEPARTMENT OF INSTRUCTIONAL LEADERSHIP AND ACADEMIC CURRICULUM

BY

____
Dr. Edmund A. Marek, Chair

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Dr. Timothy A. Laubach

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Dr. Kerry V. Magruder

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Dr. Stacy L Reeder

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Chapter I

"The teacher of biology has an opportunity—and an obligation—to point out some of the practical implications of Darwinian theory . . . . A thoughtful biologist cannot fail to find (in Shakespeare's words) 'tongue in trees, books in the running brooks, sermons in stones . . . .' If he is interested in people as well as in things . . . he will want to help students hear the sermons" (Hardin, 1973, p. 15).

Background

The most powerful theory within the biological sciences is that of evolution (Rutledge & Warden, 2000). Biological evolutionary explanations pervade all fields in biology and brings them together under one theoretical umbrella (Colby, 1996). This umbrella allows for the investigation of a broad spectrum of intriguing biological questions concerning the tremendous diversity of life on earth in a scientifically meaningful manner. In the presence of biological evolutionary theory, the multitude of traits and behaviors of organisms take on meaning (Rutledge & Warden, 2000) and in its absence, biological questions remain shrouded in mystery. So important is biological evolution theory to the field of biology that the eminent geneticist and evolutionary biologist Theodosius Dobzhansky titled his benchmark 1973 essay, *Nothing in Biology Makes Sense Except in the Light of Evolution* (p.125). Not only is a working knowledge of biological evolution instrumental in the field of biological sciences, biological evolution is one of the most important concepts in attaining scientific literacy (Alters & Alters, 2001). Nelson (2008) ponders, ". . . what could have really been accomplished in a biology course if students left it without understanding evolution and the powerful evidence on which it is based?" (p. 223).

The theory of evolution explains the mechanisms by which organisms change over time, become more complex, and diversify into new species (University of Oklahoma Department of Zoology [UODZ], 2006). Evolutionary theory serves as an extraordinarily powerful problem solving tool that has changed the way we approach each and every biological problem (Scharmann, 2005). Evolutionary principles have proved to be increasingly important in areas of human health such as antibiotic resistance, function of the human genome, and emerging diseases. In addition, evolutionary theory has resulted in improvement in both livestock and crops (Oklahomans for Excellence in Science Education [OESE], n. d.). In the 150 years since Darwin, evolutionary theory has spurred entirely new disciplines of biology including biogeography, behavioral and evolutionary ecology, evolutionary medicine, and genomics (UODZ, 2006). Not only is evolution the organizing principle of modern biology, its ". . . simple but powerful principles and algorithms have colonized scholarly disciplines formerly as remote from biology as economics, engineering, and literature" (Gross, Goodenough, Haack, Lerner, Schwartz, & Schwartz, 2005, p. 26).

There is no controversy in the scientific community about the fact of evolution (OESE, n. d.), which is supported by independent evidence from paleontology, geology, genetics, molecular biology and genomics, developmental biology, biogeography and behavior ecology (UODZ, 2006). The overwhelming majority of scientists accept the principles of evolutionary theory (Oklahoma Academy of Science [OAS], 2007) and scientists recognize that evolution is the unifying theme that underlies the biological sciences (Kennedy, 2005). Within the realm of the biologist, there is little argument that evolution has and is happening (American Association for the Advancement of Science, 1989; Moore, 2000; National Academy of Science, 1999; National Association of Biology Teachers, 1995; National Research Council, 1985; Nelson & Skehan, 2000; OAS, 2007; Rutledge & Warden, 1999).

Whereas the scientific community embraces the theory of biological evolution, the majority of the general public greets evolution with a skeptical and less than enthusiastic response. Public resistance to accepting evolution appears to have grown even as the strength of the evidence supporting evolution has increased markedly in the advancing molecular era of biology (Nelson, 2008). On the eve of the 200th anniversary of Charles Darwin's birth, a February 11, 2009 Gallup Poll indicated that only 39% of Americans say they believe in the theory of evolution, while 25% say they do not believe in the theory, and another 36% don't have an opinion either way (Newport, 2009, ¶ 1). The poll results also indicated that only 55% of Americans could correctly name evolution (or another term closely associated with evolution, such as natural selection) when asked with which theory they associate Darwin (Newport, 2009). Gregory (2009) laments, “The unavoidable conclusion is that the vast majority of individuals . . . lack a basic understanding of how adaptive evolution occurs” (p. 172).

Not only does the general public largely lack an understanding of biological evolution (Abraham, Meir, Perry, Herron, Maruca, & Stal, 2009), many adhere to misconceptions concerning the theory (Miller, 1999). These misconceptions can range from minor misunderstandings to complete theory rejection (Alters & Alters, 2001; Dagher & BouJaoude, 2005; Evans, 2001; Mazur, 2004; McComas, 2006; Sadler, 2005). When asked their views on the idea that human beings developed over millions of years from less advanced forms of life, 53% of participants in a 2007 Gallup Poll responded “definitely true” or “probably true” whereas 44% responded “probably false” or “definitely false” (Newport, 2009, Table B). Results from a National Science Foundation [NSF] 2001 nationwide survey disclosed that approximately 55% of United States respondents answered “True” to the statement, “The earliest humans lived at the same time as the dinosaurs” (p. 7-16, Figure 7-6). Approximately one third of the population thinks evolution means human beings have developed from apes (People for the American Way Foundation [PAWF], 2000). Only 29% of the PAWF 2000 national survey respondents who had heard of evolution felt that evolution was “. . . ‘completely’ or ‘mostly accurate’ while the remaining 71% responded ‘mostly not accurate,’ ‘completely not accurate,’ ‘not sure,’ or ‘might or might not be accurate, you can never know for sure’” (p. 40). Interestingly, even though many Americans are illiterate concerning evolution, the overwhelming majority (83%) want evolution taught in public schools (PAWF, 2000).

As students and teachers are functioning components of the general public, it is reasonable to assume that these two groups reflect to some degree the public’s misunderstanding of biological evolution. Some 8,400 papers, reviews, and books have been published addressing students’ and teachers’ conceptions in science (Duit, 2009). Some of these conceptions prove to be lacking or completely inaccurate misconceptions which lead the possessor to an obscured view of reality. Such student and teacher-held misconceptions have been documented in many areas of the biological sciences including that of biological evolution (Sinclair & Baldwin, 1995; Sinclair & Pendarvis, 1998).

It is not uncommon for students at all levels to have various misconceptions about evolutionary theory (Sinclair & Baldwin, 1995; Sinclair & Pendarvis, 1998). Secondary school students are known to possess low levels of evolutionary knowledge and high levels of evolutionary misconceptions (Cavallo & McCall, 2008; Clough & Wood-Robinson, 1985; Demastes, Settlage, & Good, 1995) Numerous studies have identified multiple biological evolution-related misconceptions held by secondary students (e.g., Beardsley, 2004; Bizzo, 1994; Clough & Wood-Robinson, 1985; Creedy, 1993; Deadman & Kelly, 1978; Demastes, Settlage, & Good, 1995; Evans, 2000; Geraedts & Boersma, 2006; Halldén, 1988; Jiménez-Aleixandre, 1992; Jungwirth, 1975; Kampourakis & Zogza, 2007, 2008, 2009; Lawson & Thompson, 1988; Palmer, 1999; Pedersen & Halldén, 1992; Prinou, Halkia, Skordoulis, 2008; Settlage, 1994; Shtulman, 2006; Spindler & Doherty, 2009; Tamir & Zohar, 1991). Such misconceptions about biological evolution are typically prevalent and persistent throughout the student population. Categories of biological evolution misconceptions held by students include: misconceptions about science, scientific methodology, and terminology; misconceptions of the intentionality of evolution; misconceptions of the nature of evolution; misconceptions about mechanisms of evolution; and, misconceptions about evidence supporting evolution (Alters & Alters, 2001; Bishop & Anderson, 1990; Greene, 1990; Gregory, 2009; Jensen & Finley, 1996; Wandersee, Mintzes & Novak, 1994; Wescott & Cunningham, 2005; Wilson, 2001).

In order to eliminate student misconceptions concerning biological evolution, it is important to identify their sources (Modell, Michael & Wenderoth, 2005; National Research Council, 1996; Novak, 2002; Wescott & Cunningham, 2005). Thus, much recent research concerning student-held misconceptions about biological evolutionary theory deals with the causative agents of these pervasive misconceptions. However, identifying such sources is a complex undertaking as there are several types of misconceptions as well as many mistaken assumptions on which those misconceptions are based (Committee on Undergraduate Science Education, 1997). In order to identify sources of student biological evolution misconceptions, not only must the types of misconceptions be considered, but so also must the variety of factors that influence the development of such perceptions (Hokayem & BouJaoude, 2008).

Alters and Nelson (2002) identified five classes of student-held biological evolutionary misconceptions. From-experience misconceptions are those that individuals surmise either consciously or unconsciously from their everyday experiences (Alters & Nelson, 2002; Gregory, 2009; Sinatra, Brem & Evans, 2008) whereas self-constructed misconceptions occur when information that individuals see or hear conflicts with what they already know and they accommodate the new knowledge in the framework of an old misconception (Alters & Nelson, 2002). Vernacular misconceptions are attributed to language usage (Jacobs, 1989; Lawson & Thompson, 1988; Veiga, Costa Pereira & Maskill, 1989; Yip, 1998) and religious and myth-based misconceptions are concepts in religious and mythical teachings that, when transferred into science education, become factually inaccurate (Alters & Nelson, 2002). Taught-and-learned misconceptions are misconceptions that have been taught by parents, teachers, and others, or unconsciously learned from fiction (Alters & Nelson, 2002).

Given that most teachers experience the same levels of science education as the general public, it is expected that they too will hold the same biological evolution misconceptions (Nadelson, 2009). Sadly, high levels of biological evolutionary misconceptions are known to be possessed by science teachers (Affanato, 1986; Nehm & Schonfeld, 2007; Osif, 1997) and teachers frequently subscribe to the same misconceptions as their students (Wandersee et al., 1994). Nationwide, only 57% of biology teachers consider evolution to be a unifying theme in biology (Moore, 2000); 30% of U. S. biology teachers reject the theory of evolution (Alters & Alters, 2001); and, 63% of students preparing to teach secondary science want other views to be taught with evolution (Moore & Kraemer, 2005). Gregory (2009) laments, "It is particularly disconcerting and undoubtedly exacerbating that confusions about natural selection are common even among those responsible for teaching it" (p. 163).

Substantial numbers of biology students continue to move through the education system, performing well on exams, successfully complete a biology major, and become biology teachers while still retaining major misconceptions concerning biological evolution (Bishop & Anderson, 1990; Brumby, 1984, Demastes, Good, & Peebles, 1995; Nehm et al., 2008; Nehm & Schonfeld, 2007; Settlage, 1994). Therefore, one cannot assume that biology teachers with extensive backgrounds in biology have an accurate working knowledge of biological evolution (Nehm and Schonfeld, as cited in Gregory, 2009). Despite the fact that most biology teachers have demonstrated competency in biology content, research has shown they continue to harbor major misconceptions concerning biological evolution (e.g., Bishop & Anderson, 1990; Brumby, 1984; Chinsamy & Plagányi, 2007; Clough & Wood-Robinson, 1985; Demastes, Settlage, & Good, 1995; Greene, 1990; Nehm & Schonfeld, 2007; Settlage, 1994).

Secondary school biology teachers serve as an important link between scientists' understanding and the general public's understanding and perception of biological evolution (Nehm & Schonfeld, 2007). Sadly, however, teachers continue to be poorly prepared to teach evolution (Moore & Kraemer, 2005). Moore (2004) found that "many of today's high school teachers don't recall hearing the word *evolution* in their college biology courses" (p. 864). Only about one-third of secondary biology teachers feel that their undergraduate methods classes prepared them to teach evolution (Moore & Kraemer, 2005) and the same proportion either resist or avoid teaching evolution (Weld & McNew, 1999). It is not surprising then that teachers may misunderstand and misuse the theory of biological evolution (Anderson, Fisher, & Norman, 2002; Bishop & Anderson, 1990; Rudolph & Stewart, 1998). In addition, teachers, like others who hold beliefs and conceptions very tightly, may not be prepared to consider alternative explanations or be motivated to engage in situations that challenge their perspectives (Hoy, Davis, & Pape, 2006; Pajares, 1992).

Teachers' knowledge, attitudes and beliefs about a subject affect the teachers' curriculum and instructional decisions (Carlesen, 1991; Grossman, 1989).
"In instructor-centered teaching, the instructor solely determines, primarily from tradition and disciplinary content, exactly what is to be taught and how it should be taught—most often presenting content to students as if it were capable of being merely transferred" (Alters & Nelson, 2002). In other words, teachers continue to teach as they were taught (Alters & Nelson, 2002; Tobin, Tippins, & Gallard, 1994) and convey acquired knowledge—be it accurate or inaccurate—to their students. Based on the extensive research indicating in secondary life science teachers the prevalence of

inadequate or misconception-riddled knowledge of biological evolution, teacher transmission of misconceptions of biological evolution appears to be inevitable and no doubt pervasive within the secondary school. Jarvis, Pell, & McKeon, (2003) concur: ". . . educators are nearly certain to teach their misconceptions to their students" (as cited in Nadelson, 2009, p. 492).

Problem Statement

As previously cited, the present level of biological evolution knowledge possessed by students, teachers, and other members of society is quite lacking and typically fraught with misconceptions. Randy Moore, former editor of the *American Biology Teacher*, states, "It [evolution education] is by far the biggest failure of science education from top to bottom" (as cited in Alters & Alters, 2001, p. 103). Quite surprisingly then, evolution education is woefully under-researched (Wiles & Asghar, 2007). Dr. Brian Alters, Associate Professor of Science Education at McGill University, relates: "It's [evolution education] incredibly under-researched. It's a very sensitive topic. A lot of people would rather not go into a field that upsets people as much as evolution" (as cited in McCabe, 1999, ¶10). The lack of educational research concerning biological evolution education is quite disturbing particularly if the battle over evolution education is, as the late, eminent evolutionist, Stephen Jay Gould wrote, ". . . one of the most important issues of our age" (as cited in Alters & Alters, 2001, p. 1). Recently, a coalition of 17 organizations, including the National Academy of Sciences, the American Institute of Physics, and the National Science Teachers Association, called on the scientific community to become more involved in the promotion of science education, including evolution (Coalition of Scientific Societies, 2008). In addition, research by the American Association for the Advancement of Science, National Research Council, National Association of Biology Teachers, and National Science Teachers Association have all called for studies on the teaching and learning of evolution (Maldonado-Rivera, 1998).

Even though "There is evidence indicating that many science misconceptions may actually have been taught by teachers to their students" (Alters & Nelson, 2002; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Fisher, 2004); ". . . instruction in evolutionary biology at the high school level has been absent, cursory, or fraught with misinformation" (Rutledge & Mitchell, 2002) and, ". . . views of evolution are reinforced with sloppy descriptions by trusted authorities" (Jungwirth, 1975, 1977; Moore, Mitchell, Bally, Inglis, Day, & Jacobs, 2002) little formal research has addressed secondary school life science teacher contributions to student acquisition of biological evolution-related misconceptions. When one considers that students in secondary school often retain their misconceptions despite receiving formal training in biology (Lawson & Thompson, 1988), one must question the levels of evolutionary knowledge and misconceptions possessed by secondary life science instructors through whose classrooms these students pass. Shulman (1986) has recognized the lack of research into teacher subject matter knowledge as a "blind spot" in science education, referring to it as the missing paradigm (p.7).

The question therefore begs: *What is the role of the secondary school life science instructor in student acquisition of biological evolution-related misconceptions?* I will gather data to address the following questions: (a) What biological evolution-related misconceptions are held by secondary school life science teachers? (b) What biological evolution-related misconceptions are held by secondary school life science students prior to instruction in biological evolution curriculum? (c) What biological evolution-related misconceptions are held by secondary school life science students following instruction in biological evolution curriculum? (d) Are biological evolution-related misconceptions held by secondary school life science teachers transmitted to their students by way of instruction in biological evolution curriculum?

Chapter II

Literature Review

The purpose of this literature review is to provide a scholarly foundation for the present study of secondary school life science teachers as a source for student-held misconceptions about biological evolution. Following the format established by Glatthorn (2002), the review begins by clarifying the parameters of the study and explaining the search-and-retrieval process. The body of the review is organized by the results of the study which consider the following: (a) definition of the terms *biological evolution* and *misconception;* (b) identification of misconceptions of biological evolution held by students; (c) identification of misconceptions of biological evolution held by teachers; and, (d) origination of biological evolutionary misconceptions. A concluding paragraph discusses the implications of the findings.

Before presenting the results of this literature review, it would be helpful to review the search process. The review process began with a search of several databases including—but not limited to—the University of Oklahoma's Library Online Resource Access, Education Resources Information Center, and EBSCO. Search parameters were set which included the focus of the study; a time frame of 35 years (1974 to present) with the exception of foundational research published prior to the 35 year time frame; and, types of articles investigated which included both qualitative and quantitative empirical research, reviews of literature, and meta-analysis. Search descriptors included—but were not limited to—e*volution, misconceptions, origination, student,* and *teacher.* Sources identified were subject to a quality check. Only those studies meeting quality standards were selected for this literature review. These quality standards eliminated studies which possessed evidence of bias, unsupported claims, questionable tests or measurements, or small sample size.

Definitions

Evolution

Regardless of what opinions people may hold concerning the evolution of humans and other organisms, many obviously do not seem to understand the meaning of *evolution*. Although just about all Americans (95%) have heard of evolution, fewer than half say they are very familiar with it and for those who recall ever having heard the term *evolution*, only 50% chose the correct layman's definition (People for the American Way Foundation [PAWF] 2000). Of the 59% of nonmajor biology students that accepted evolution in a 2007 study, only 6% could correctly explain it and a surprisingly high percentage (8%) independently described the big bang theory instead of the theory of biological evolution (Robbins & Roy, 2007). In the 150 years since Darwin published *Origin of Species,* much has been written and debated about what evolution is and, for that matter, what evolution is not. In order to accurately review the research literature associated with biological evolution misconceptions, an accurate definition of evolution is required.

The term *organic evolution* is often used synonymously with biological evolution, distinguishing biological evolution from both chemical and cosmic evolution (Bird, 1991). In *Evolutionary Biology* (1998), Douglas J. Futuyma defines biological evolution as follows:

> Biological (or organic) evolution is change in the properties of populations of organisms or groups of such populations, over the course of generations. The

> development, or ontogeny, of an individual organism is not considered evolution: individual organisms do not evolve. The changes in populations that are considered evolutionary are those that are heritable via the genetic material from one generation to the next. Biological evolution may be slight or substantial; it embraces everything from slight changes in the proportions of different forms of a gene within a population, such as the alleles that determine the different human blood types, to the alterations that led from the earliest organisms to dinosaurs, bees, snapdragons, and humans. (p. 4)

The study of biological evolution is traditionally divided into two fields identified as microevolution and macroevolution (Riddiford & Penny, 1984). Gould defines microevolution as "evolutionary changes within local populations, up to the origin of new species" (as cited in Luria, Gould, & Singer, 1981, pp. 773-774). This change beneath the species level may be thought of as relatively small scale change in the functional and genetic constituencies of local populations (Volpe, 1985). Macroevolution, as defined by Gould, is "evolutionary change above the species level" (as cited in Luria et al., 1981, pp. 773-774). Macroevolution is evolution on the grand scale resulting in new species and the origination of higher taxa via microevolutionary processes and environmental influences. Microevolution and macroevolution are interdependent and one cannot occur without the other (Mayr, 2001).

Often confused within the mix of the evolution lexicon is the term *Darwinism.* Initially coined by staunch Darwin supporter Thomas Henry Huxley in an April, 1860 review of Darwin's *Origin of Species* in *Westminster Review*, Darwinism identifies a core set of concepts, principles and methodological maxims that were first articulated and defended by Charles Darwin and which continue to be identified with a certain approach to evolutionary questions (Lennox, 2004). Evolution and Darwinism are not synonymous (Good, 1974) as lamented by Zoologist R.T. O'Grady, ". . . the model developed to explain evolution has come to be seen as evolution itself" (1984, p. 563). Darwinism describes the theoretical mechanisms acting in microevolution which account for macroevolution. Darwinism is not a simple theory that is either true or false but rather a highly complex research program that is being continuously modified and improved (Hanes, n. d.). Ernst Mayr (1991), arguably the greatest evolutionary theorist since Darwin (Shermer, 2006), partitioned Darwinism into five theoretical mechanisms: (a) evolution as such; (b) common descent; (c) multiplication of species; (d) gradualism; and (d) natural selection (as cited in Hanes, n. d.).

For Mayr (1991), evolution as such is the theory that the world is not constant or recently created nor perpetually cycling, but rather is steadily changing, and that organisms are transformed in time. In turn, common descent is a general descriptive theory that concerns the genetic origins of living organisms (though not the ultimate origin of life) and their resulting relationships. Common descent describes the theory that every group of organisms descended from a common ancestor and that all groups of organisms ultimately go back to a single origin of life on earth (Mayr, 1991). As Kluge (1977) notes: ". . . each and every species, living and dead, is linked by genealogical descent and common ancestry" (p. 22).

Multiplication of species explains the origin of the enormous organic diversity on planet Earth. This theory postulates that species multiply either by splitting into daughter species or by the establishment of geographically isolated founder populations that evolve into new species (Mayr, 1991). Thus, macroevolutionary history and processes necessarily entail the transformation of one species into another and, consequently, the origin of higher taxa (Freeman & Herron, 2004; Futuyma, 1998; Ridley, 1993).

While gradualism pictures evolutionary change through the gradual change of populations and not by the sudden production of new individuals that represent a new type (Mayr, 1991), Darwin's most recognizable evolutionary theory, natural selection, is the process by which individuals with beneficial traits survive and reproduce more frequently, on average, than individuals with less favorable traits (Kardong, 2008). The relatively few individuals who survive, owing to a particularly well-adapted combination of inheritable characters, give rise to the next generation (Mayr, 1991). To constitute natural selection, the difference in survival and reproduction cannot be due to chance, and it must have the potential consequence of altering the proportions of the different entities (Futuyama, 2005). Natural selection is one of the core mechanisms of evolutionary change and is the main process responsible for the complexity and adaptive intricacy of life (Gregory, 2009).

Misconception

A misconception is defined as "a perception of phenomena occurring in the real world which is not consistent with the scientific explanation of the phenomena" (Modell, Michael, & Wenderoth, 2005, p. 20). In broad terms, misconceptions correspond to the concepts that have peculiar interpretations and meanings in an individual's articulations that are not scientifically accurate (Bahar, 2003). Snively (1990) contends that misconceptions are rooted in a cluster of prior ideas, beliefs, values, and emotions that serves as the initial set of interpretive categories (as cited in Dagher & BouJaoude, 1997).

Misconceptions regarding the nature of science and evolutionary theory are typically complex and strongly held, and can interfere with students' abilities to understand accurate scientific explanations that are presented in class (Bishop & Anderson, 1990; Brumby, 1984; Cunningham & Wescott, 2009; Ferrari & Chi, 1998; Jiménez & Fernández-Pérez 1987; Wilson, 2001). These misconceptions surrounding biological evolution can range from minor misunderstandings to complete theory rejection (Alters & Alters, 2001; Dagher & BouJaoude, 2005; Evans, 2001; Mazur, 2004; McComas 2006; Sadler, 2005). Therefore, misconceptions are fundamental barriers to understanding how evolution operates (Cunningham & Wescott, 2009; Meir, Perry, Herron, & Kingsolver, 2007).

As cited in Bahar, 2003, misconceptions are also referred to as naïve beliefs (Caramazza, McCloskey, & Green, 1981), erroneous ideas (Fisher, 1985), preconceptions (Hashweh, 1987), multiple private versions of science (McClelland, 1984), underlying sources of error (Fisher & Lipson, 1986), personal models of reality (Champagne, Gunstone, & Klopfer, 1983), spontaneous reasoning (Viennot, 1979), persistent pitfalls (Meyer, 1987), common sense concepts (Haloun & Hestenes, 1985), spontaneous knowledge (Pines & West, 1986), alternative frameworks (Driver & Easley, 1978), and children science (Gilbert, Watt, & Osborne, 1982). Some researchers (e.g., Abimbola, 1988; Gilbert & Swift, 1985; Wandersee, Mintzes, & Novak, 1994) prefer the term *alternative conception* (as cited in Bahar, 2003). In order to eliminate confusion, the term *misconception* will be used in this literature review for the following reasons: (a) the term misconception is dominant in the literature; (b) the term is already familiar with the public, and (c) the term easily conveys the message that a concept might have contradictory connotations with the current scientific thought in science education (Bahar, 2003).

Identification of Student-held Biological Evolution Misconceptions

Students bring a diverse array of ideas about natural events to their sciences classes, and many of these ideas are often at variance with the scientifically accepted views. Numerous studies conducted in recent decades identify multiple biological evolution-related misconceptions held by select groups of students. These groups include: secondary students (Beardsley, 2004; Bizzo, 1994; Clough & Wood-Robinson, 1985; Creedy, 1993; Deadman & Kelly, 1978; Demastes, Settlage, & Good, 1995; Evans, 2000; Geraedts & Boersma, 2006; Halldén, 1988; Jiménez-Aleixandre, 1992; Jungwirth, 1975; Kampourakis & Zogza, 2007, 2008, 2009; Lawson & Thompson, 1988; Palmer, 1999; Pedersen & Halldén, 1992; Prinou, Halkia, & Skordoulis, 2008; Settlage, 1994; Shtulman, 2006; Spindler & Doherty, 2009; Tamir & Zohar, 1991); first year undergraduate students (Brumby, 1979; Jensen & Finley, 1995; Nehm & Reilly, 2007; Sundberg & Dini, 1993); second year undergraduate students (Jiménez-Aleixandre & Fernández-Pérez, 1987) collective undergraduate students (Anderson, Fisher, & Norman, 2002; Bishop & Anderson, 1990; Brem, Ranney, & Schindel, 2003; Chinsamy & Plaganyi, 2007; Cunningham & Wescott, 2005; Demastes, Settlage et al., 1995; Ferrari & Chi, 1998; Hokayem & BouJaoude, 2008; Jensen & Finley, 1996; Meir et al., 2007; Paz-y-Mińo C. & Espinosa, 2009; Robbins & Roy, 2007; Shtulman, 2006); medical students (Brumby, 1984); and, physics doctoral students (Chan, 1998).

Collectively, these studies repeatedly indicate that students of all ages—from middle school through university students—have difficulties accurately understanding the concepts of evolution (Stern & Ben-Akiva, 2007).

Categories of student misconceptions of biological evolution employed by this review were developed and organized based on the major areas of biological evolution misconceptions generated by several researchers (e.g., Alters & Alters, 2001; Bishop & Anderson, 1990; Cunningham & Wescott, 2005; Greene, 1990; Gregory, 2009; Jensen & Finley, 1996; Wandersee et al., 1994; Wilson, 2001). These categories include:
(a) misconceptions of science, scientific methodology and terminology;
(b) misconceptions of the intentionality of evolution; (c) misconceptions of the nature of evolution; (d) misconceptions of mechanisms of evolution; and, (e) misconceptions of evidence supporting evolution.

Misconceptions of Science, Scientific Methodology and Terminology

The word *theory* is perhaps the most misunderstood word in science (Scott, 2004). In everyday usage, *guess* or *hunch*—terms that imply speculation or conjecture—are synonyms for theory. Yet according to the National Academy of Sciences [NAS], a theory is defined as "a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses" (1998, p. 7). Students who possess misconceptions of scientific theory typically understand theory in the speculative sense (Alters & Alters, 2001; Dagher & BouJaoude, 1997; Smith & Sullivan, 2007) as in *evolution is only a theory*. Darwin himself insisted that theory comes to and from the facts, not from political or philosophical beliefs (as cited in Shermer, 2006). Related to the misuse of the term theory are student misconceptions of biological evolution-related theories. In a study of university nonmajor biology student undergraduates, Robbins and Roy (2007) discovered only 6% of the 141 participants understood the nature of evolutionary theory. Theory does not stand alone as a term which fosters misconceptions; research indicates nonmajor biology students reinforce their misconceptions by confusing the scientific terms *adapt*, *adaptation,* and *fitness* with the common usage of the terms (Bishop & Anderson, 1986, 1990).

A basic premise in evolutionary theory is the existence of large expanses of time required for evolutionary processes to occur. Students hold misconceptions related to the evolutionary time scale with many believing that evolution occurs over centuries rather than tens and hundreds of millennia (Robbins & Roy, 2007). Alternatively, misconceptions conferring a young age to the earth may lead students to the subsequent misconception that the earth is not old enough for evolution to have occurred (Alters & Alters, 2001; Smith & Sullivan, 2007). Dating techniques provide evidence of the timeline of evolution (Shermer, 2006). Alters & Alters (2001) lamented the number of students who have come to believe that dating techniques are questionable while Scott (2004) detailed 20 such misconceptions. Chief among Scott's misconceptions are the ideas that different dating techniques usually give conflicting results and the decay rates of radioactive dating elements are poorly known. Based on these misconceptions, students view calculated dates as inaccurate.

The second law of thermodynamics holds that in a closed system energy tends to travel from organized to disorganized states in the form of heat (Futuyma, 1995). If students fail to understand that life operates within an open system that possesses a constant inflow of energy, then a commonly-held misconception develops that describes evolution in violation of the second law of thermodynamics. Such a misconception precludes complex organisms evolving from simpler ones (Alters & Alters, 2001; Berra, 1990; Futuyama, 1995; Scott, 2004; Smith & Sullivan, 2007).

Misconceptions of the Intentionality of Evolution

Misconceptions associated with evolution intentionality subscribe a type of conscious will and directive to the mechanisms of evolution. These misconceptions can be arranged into three related classes: (a) teleology, (b) determinism, and (c) need. Much of the human experience involves fulfilling needs as one attempts to overcome obstacles in order to achieve goals. Consequently there seems to be a powerful psychological bias toward imparting thoughts concerning purpose or function to non-human objects, processes, and behaviors. Combining this bias with egocentrism and anthropomorphism, students often perceive evolution as purposeful change that responds to needs—since we make things with intent, nature must also make things with intent (Smith & Sullivan, 2007). This tendency toward biological evolution explanations based on purpose is termed *teleology* and is common and persistent throughout secondary school (Alters & Nelson, 2002; Jensen & Finley, 1996; Kampourakis & Zogza, 2007; Passmore & Stewart, 2002; Samarapungavan & Wiers, 1997; Southerland, Abrams, Cummins, & Anzelmo, 2001) and even into postsecondary education (Kelemen & Rosset, 2009). In a study of university nonmajor biology students, Jensen and Finley (1996) identified the most common misconception responses were related to teleology.

Teleological explanations are very common in misconceptions of adaptation (Abraham et al., 2009; Bishop & Anderson, 1990; Bizzo, 1994; Dagher & BouJaoude, 1997; Moore, 2002; Pedersen & Halldén, 1992; Sinatra, Brem, & Evans, 2008; Smith & Sullivan, 2007; Southerland et al., 2001; Tamir & Zohar, 1991). Abraham et al. (2009) identified that students often ascribe agency to trait shifts in populations, as if the yearnings or needs of an organism will cause a trait to change, even within that organism's lifetime. Research indicates this is a prevalent and persistent misconception. Bishop and Anderson (1990) revealed university undergraduates believed organisms could willfully change their traits or the traits of their offspring. Dagher and BouJaoude (1997) learned that college students describe a conscious selection of desired characteristics by organisms. Echoing these findings, a 2002 study found that first year university students suggested adaptive processes that are purposeful, entailing even conscious striving for evolutionary progress and advantage (Moore et al.). These explanations are teleological in the sense that changes take place in order to contribute to organisms' local adaptations (Kampourakis & Zogza, 2007).

Closely related to teleology is the misconception of biological evolution determinism (Alters & Nelson, 2002; Bishop & Anderson, 1990; Lord & Marino, 1993). Evolutionary determinists mistakenly believe evolution involves a ladder-like progression, as though nature had a innate aim to strive ever upward, rung after rung, from simple to more complex organisms, culminating in humans—the ultimate goal of evolution (Smith & Sullivan, 2007). Evolutionary determinism is likewise a common student misconception identified in many studies (e.g., Alters & Nelson, 2002; Bishop & Anderson, 1990; Bizzo, 1994; Dagher & BouJaoude, 1997; Gregory, 2009; Passmore

& Stewart, 2002; Smith & Sullivan, 2007). Students with biological evolution determinist misconceptions may view evolutionary change as gradual and progressive changes in traits, rather than as a changing proportion of individuals with discrete traits (Bishop & Anderson, 1990; Dagher & BouJaoude, 1997). Gregory (2009) discovered that students possessing such deterministic misconceptions may believe any differences between parent and offspring will be in the direction of further improvement. Bizzo (1994) found that Brazilian high school students viewed evolution as a ladder with viruses on bottom and humans on top. Because evolutionary perfection in the form of humans had been reached, many believed that evolution was no longer taking place. This supposed evolutionary march towards perfection was also identified by Dagher and BouJaoude (1997).

Evolutionary intentionality is intimately tied to misconceptions that traits arise due to a response to need or an effort to change by individual organisms themselves. This misconception is persistent and pervasive as reported in the literature (Alters & Nelson, 2002; Banet & Ayuso, 2003; Bishop & Anderson, 1990; Brumby, 1984; Clough & Wood-Robinson, 1985; Gregory, 2009; Kampourakis & Zogza, 2007; Mayr, 1982; Passmore & Stewart 2002; Samarapungavan & Wiers, 1997; Settlage, 1994). The misconception of need emphasizes that changes in organisms' traits are a result of a need to enhance survivability by producing new traits that will be useful to the organism (Alters & Nelson, 2002; Banet & Ayuso, 2003; Bishop & Anderson, 1990; Brumby, 1984; Kampourakis & Zogza, 2007; Mayr, 1982; Passmore & Stewart, 2002; Settlage, 1994). Such misconceptions frequently reference needs to some undefined, internal unconscious drive (Clough & Wood-Robinson, 1985) which can result in heritable differences between parents and offspring and thus allow the entire species to transform in response to need (Gregory, 2009). Evolution through need via purposeful change was the most common misconception identified in a recent study of secondary students' misconceptions about evolution (Kampourakis & Zogza, 2007).

Under the umbrella of misconceptions of need lies related misconceptions of use and disuse and inheritance of acquired characteristics. The misconception of use and disuse states that the more an organ or body part is used, the larger and stronger that part will become and, conversely, the less a body part is used, the smaller and weaker it becomes, eventually withering away if not used at all (Smith & Sullivan, 2007). Willful use and disuse of a structure implies evolution intentionality. Student misconception of use and disuse is deeply embedded in the literature (e.g., Alters & Nelson, 2002; Bishop & Anderson, 1990; Bizzo, 1994; Brumby, 1984; Deadman & Kelly, 1978; Demastes, Good, & Peebles, 1995; Ferrari & Chi, 1998; Gregory, 2009; Jensen & Finley, 1996; Kampourakis & Zogza, 2007, 2008, 2009; Mayr 1982; Nehm & Reilly, 2007; Passmore & Stewart, 2002; Prinou, Halkia, & Skordoulis, 2008; Samarapungavan & Wiers, 1997; Settlage, 1994).

Evolution resulting in changes in individual organisms, whether based on supposed conscious choice of need or use and disuse, implies that characteristics acquired during the lifetime of an individual be passed on to offspring. Students may sometimes see that traits such as smoking or bodybuilding have a tendency to run in some families and intuit – incorrectly – that these acquired traits are inherited (Stern & Ben-Akiva, 2007). Numerous studies have identified this misconception of inheritance of acquired characteristics in student populations (e.g., Alters & Nelson, 2002;

Anderson et al., 2002; Banet & Ayuso, 2003; Beardsley, 2004; Bishop & Anderson, 1990; Brumby, 1979; Dagher & BouJaoude, 1997; Deadman & Kelly, 1978; Ferrari & Chi, 1998; Geraedts & Boersma, 2006; Greene, 1990; Gregory, 2009; Jensen & Finley, 1996; Jiménez-Aleixandre, 1992; Jiménez-Aleixandre & Fernández-Pérez, 1987; Mayr, 1982; Passmore & Stewart, 2002;). In addition, one study found students not only attributed acquired traits to inheritance, but acquired behaviors as well (Anderson et al., 2002).

Misconceptions of the Nature of Evolution

In evolutionary theory the environment serves as the selecting agent for differing traits that arise via evolutionary processes (Berra, 1990). Because the environment changes over time and from one region to another, different variants will be selected under different environmental conditions. A common misconception among students is that the environment actually causes changes in organisms rather than affecting the survival of those traits after their appearance in the population (American Association for the Advancement of Science [AAAS], 1993; Anderson et al., 2002; Bishop & Anderson, 1990; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Gregory, 2009; Jiménez-Aleixandre, 1992). Additional misconceptions related to the environment's role in evolution suppose that environmental conditions are not considered important in causing selective pressures (Rutledge & Warden, 2002) and drastic climate change must be present for evolution to occur (Nehm & Reilly, 2007).

Students may adhere to the misconceptions that evolution proceeds by random chance. Isaak (2003) indicates there is probably no other misconception which is a better indication of a lack of understanding of evolution. With the environment selecting specific variations within populations, evolution in totality is a non-random process. However, randomness does play a role in pivotal evolutionary mechanisms including the origination of variations via both mutations and gene recombination (Smith & Sullivan, 2007). As Dawkins stated, "Darwinian evolution is the nonrandom survival of randomly varying coded information (The Wall Street Journal, p. W2). Students may not understand the role of randomness in evolution (AAAS, 1993, Driver et al., 1994); they may believe that evolution is a totally random process (Dagher & BouJaoude, 1997); or they may hold the misconception that genetic variation is nonrandom and is instead the result of external pressures (Abraham et al., 2009).

The roles of the individual and population are often confused in evolutionary theory. Students may fail to distinguish changes occurring among individual organisms from changes occurring within populations (AAAS, 1993; Driver et al., 1994). In doing so, students may incorrectly surmise that individuals, not populations, adapt to their environments (Robbins & Roy, 2007) and that populations change their traits together as a whole through a gradual change in all members (Abraham et al., 2009; Anderson et al., 2002; Stern & Ben-Akiva, 2007).

Misconceptions of Mechanisms of Evolution

The theory of natural selection calls for variations within a population. Those population members possessing variations that give them an advantage in the environment in which they reside are thus granted a reproductive advantage over those members which possess less advantageous variations. Students hold robust misconceptions concerning these and other mechanisms of evolution.

Variations are genetically determined differences in the characteristics of members of the same species (NAS, 1998, p. 13). Students may not view genetic variation as important to evolution, even though such variation is essential to evolution taking place (Alters & Nelson, 2002; Bishop & Anderson, 1990; Gregory, 2009; Mayr, 1982; Rutledge & Warden, 2002). Students may exhibit confusion about the origin and role of variation (AAAS, 1993; Driver et al., 1994; Gregory, 2009) indicating that variations arise via environmental or selection pressures (Bishop & Anderson, 1990); are rare or non-existent (Anderson et al., 2002; Gregory, 2009); are a deviation from the *essence* or *type* of the species (Gregory, 2009); or only affect outward appearance and do not influence survival (Anderson et al., 2002).

Variations within a population can originate through reproductive genetic recombination or via mutations, defined by Mayr (2001) as any alterations in the genetic material (p. 288). Multiple student misconceptions exist concerning the production and role of mutations in evolution. One such example includes mutations arising as adaptive responses to specific environmental agents—as in the development of resistance in bacteria exposed to antibiotics. This particular misconception inaccurately portrays mutations as always being beneficial (Anderson et al., 2002; Gregory, 2009). Conversely, some students describe mutations as detrimental to fitness (Alters & Nelson, 2002). Misconceptions of the intentionality of mutations exist as well with students believing mutations occur to meet the needs of the population (Anderson et al., 2002). However, mutations and genetic recombination within a population result in traits which may or may not prove to be advantageous.

As population traits are subjected to environmental factors, certain traits give their possessors a better chance of survival and therefore a corresponding better chance of reproductive success than do those population members lacking such traits. These advantageous traits are referred to as adaptations. Mayr (2001) defines adaptation as any property of an organism that is believed to add to its fitness, (i.e., reproductive success, p. 283). The literature is replete with student misconceptions of both non-adaptive and adaptive traits and their respective roles in evolution.

Students may incorrectly assume that traits are always beneficial and only these traits are passed along to offspring (Gregory, 2009); when a trait is no longer beneficial for survival, the offspring will not inherit the trait (Anderson et al., 2002); dominant traits are always selectively advantageous (Nehm & Reilly, 2007); hereditable compensation of one trait occurs when another faculty is lost, such as an improvement in hearing when blindness occurs (Nehm & Reilly, 2007); and, evolutionary change is based on gradual modifications in traits, not the changing proportion of individuals with particular alleles (Bishop & Anderson, 1990; Mayr, 1982; Rutledge & Warden, 2002). Additionally students possess misconceptions concerning how adaptive traits arise (AAAS, 1993). One such misconception describes complex adaptive trait change occurring suddenly, within a single generation (Brumby, 1984; Gregory, 2009) and another refers to the appearance of traits because of a spontaneous change in an individual's genotype (Settlage, 1994).

Natural selection is the mechanism that determines which individuals will survive long enough to reproduce and transmit their genes to the next generation. Research on student learning indicates that evolution by natural selection is one of the most difficult scientific theories to accept (Stern, 2004). A multitude of studies have revealed student misconceptions concerning natural selection (e.g., Bishop & Anderson, 1990; Beardsley, 2004; Bizzo, 1994; Brumby, 1979, 1984; Clough & Wood-Robinson, 1985; Creedy, 1993; Deadman & Kelly, 1978; Geraedts & Boersma, 2006; Jensen & Finley, 1995, 1996; Jiménez-Aleixandre & Fernández-Pérez 1987; Kampourakis & Zogza, 2007, 2008, 2009; Nehm & Reilly, 2007; Pedersen & Halldén, 1992; Prinou et al., 2008; Shtulman, 2006; Spindler and Doherty, 2009; Tamir & Zohar, 1991). Students may incorrectly interpret natural selection as a particular event, rather than as a process (Ferrari & Chi, 1998; Sinatra et al. 2008) and may also conceive natural selection as being *all or nothing* with all unfit individuals dying and all fit individuals surviving (Gregory, 2009). In addition, students may fail to distinguish natural selection from the origin of new variations (Creedy, 1993; Greene, 1990; Moore et al., 2002). Student may also believe the complex structures such as eyes or wings could not have been formed by natural selection since intermediate steps would seem to be inviable or nonfunctional (Nelson, 2008).

Many student-held misconceptions about natural selection involve misinterpretation of the phrase, *survival of the fittest*, the most commonly used phrase drafted into everyday speech from the theory of evolution (Smith & Sullivan, 2007). Darwin (1872) defined survival of the fittest as: "[The] preservation of favourable individual differences and variations, and the destruction of those which are injurious" (p. 63). Students commonly identify the meaning of survival of the fittest as survival of the fittest species (Nehm & Reilly, 2007), i.e., relating fitness directly to physical strength, speed, intelligence or longevity (Anderson et al., 2002; Bishop & Anderson, 1990; Robbins & Roy, 2007) or even the number of mates possessed (Anderson et al., 2002). Students view survival of the fittest also as physical fighting among different species with the strongest species winning (Anderson et al., 2002). Students also inaccurately relate fitness to inheritance where fit refers to dominant and unfit refers to recessive, in the allelic sense (Nehm & Reilly 2007).

Misconceptions of Evidence Supporting Evolution

Scientific evidence supporting biological evolution theory is abundant, diverse, and compelling, ranging from the homology of DNA to the fossil record (Alters & Alters, 2001; Belk & Borden-Maier, 2010; Futuyama, 1998; Ridley, 1996; Shermer, 2006). However, a 2004 Gallup Poll reveals only 34% of Americans think that Charles Darwin's theory of evolution is well-supported by the evidence. Many students harbor misconceptions concerning such evidence with perhaps no area of evolution more fraught with misconceptions than that of the evolutionary history of humans. Although biological evolution theory tells us that humans and modern apes evolved in present-day Africa from common primate ancestors some six million years ago (Smith & Sullivan, 2007), a common misconception voiced by students is that humans evolved from monkeys, gorillas, or apes (Dagher & BouJaoude, 1997; Lord & Marino 1993; Robbins & Roy, 2007; Smith & Sullivan, 2007). In fact, a 1993 study of university students found that 42% of students questioned stated humans evolved from monkeys (Lord & Marino, 1993). In addition, Shields (2004) identified many misconceptions students currently hold concerning modern humans. These misconceptions include: the pinky toe is getting smaller or disappearing; wisdom teeth will disappear; the appendix is getting smaller or disappearing; humans are taller than in 1700 due to evolution; people are evolving to be smarter in response to new technologies; and, new human species are being formed.

The most convincing evidence for the occurrence of evolution is the discovery of fossils of extinct organisms in older geological strata (Mayr, 2001). Yet, student misconceptions abound concerning fossil evidence of evolution. Some believe fossils are rare and more or less haphazardly distributed across the landscape (Nelson, 2008). Another common misconception concerns a lack of transitional fossils—commonly called missing links (Alters & Alters, 2001; Isaak, 2003; Smith & Sullivan, 2007) even though thousands of these fossils representing intermediates between two lineages have been discovered (Isaak, 2003). Based on a perceived fossil record, student misconceptions accept the coexistence of humans and dinosaurs even though evidence indicates the two groups are separated by approximately 65,000,000 years (Alters & Alters, 2001; Alters & Nelson, 2002).

Identification of Teacher-held Biological Evolution Misconceptions

Misconceptions are held by both novices and experts alike (Palmquist & Finley, 1997). Therefore, it is logical that teachers should hold a range of misconceptions (Kikas, 2004). The general public is known to harbor many misconceptions concerning biological evolution and, given that most teachers experience the same levels of science education as the general public, it is expected that they too will hold the same misconceptions concerning biological evolution (Nadelson, 2009). As Nehm and Schonfeld (2007) recently concluded, "one cannot assume that biology teachers with extensive backgrounds in biology have an accurate working knowledge of evolution, natural selection, or the nature of science" (p. 716). In fact, research indicates that teachers hold many of the same biological evolution misconceptions as do their students (Bishop & Anderson, 1990; Brumby, 1984; Demastes, Good et al., 1995; Nehm & Schonfeld, 2007; Settlage, 1994). Although literature citing teacher misconceptions about biological evolution is not as extensive as that of student-held misconceptions, research has addressed such misconceptions in both preservice teachers (e.g., Asghar, Wiles, & Alters, 2007; Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Deniz, Donnelly, & Yilmaz, 2008; Greene, 1990; Jiménez-Aleixandre, 1994; Jungwirth, 1977; Nadelson, 2009; Vlaardingerbroek & Roederer, 1997) as well as practicing teachers (e.g. Affanato, 1986; Berkman, Pacheco, & Plutzer, 2008; Bishop & Anderson, 1990; Brumby, 1984; Graf, as cited in Curry, 2009; Jiménez-Aleixandre, 1994; Jungwirth, 1977; Moore & Kraemer, 2005; Nehm & Schonfeld, 2007; Osif, 1997; Rutledge & Warden, 2002; Tatina, 1989; Tidon & Lewontin, 2004; Zimmerman, 1987).

A 1999-2000 National Center for Education Statistics report (Indicator 28, as cited in Wiles, 2008) found that over a third of high school biology teachers were not biology majors. Therefore, in this review of biological misconceptions held by teachers, no distinction is made between preservice teachers, teachers, and biology teachers. Additionally, the level of biological evolution misconceptions held by biology teachers is not dependent on the extent of their biology education (Nehm & Schonfeld, 2007).

Misconceptions of Science, Scientific Methodology and Terminology

Research reveals that teachers hold misconceptions related to the nature of science and how it pertains to the teaching of evolution (Moore & Kraemer, 2005; Nadelson, 2009; Nehm & Schonfeld, 2007; Rudolph & Stewart, 1989; Rutledge & Warden, 2002). Fifteen percent of participants in a study of Minnesota high school biology teachers believed that evolution was not a scientifically valid idea (Moore & Kraemer, 2005). For some secondary teachers, evolution cannot be proven or evolution must be seen in order to be true (Nehm & Schonfeld, 2007).

As with students, teachers labor under misconceptions involving scientific terminology (Bybee, 2001; Jiménez-Aleixandre, 1994; Nehm & Schonfeld, 2007; Nehm & Sheppard, 2004; Scharmann & Harris, 1992). In a study of K-12 preservice teachers, participants viewed theories as tentative ideas with limited credibility and not as evidence-based explanations (Nadelson, 2009). Based on this common misconception about scientific theory, teachers may view evolution as a weak science and indicate that evolution should be taught *only as a theory* and not as fact (Bybee, 2001, Nadelson, 2009; Nehm & Schonfeld, 2007).

Some teachers seem to share pupils' difficulties when trying to interpret instances of biological change (Jiménez-Aleixandre, 1994), and many doubt the currently accepted scientific determination of the age of the Earth (Rutledge & Warden, 2002). In a 2008 study of 939 high school biology teachers, Berkman et al. (2008) discovered that one in six held young Earth views.

Misconceptions of the Intentionality of Evolution

Teachers are known to ascribe teleological misconceptions to biological evolution (Jungwirth, 1977; Tatina, 1989). When asked to describe the process of biological evolution, 27% of South Dakota teachers and 22% of Ohio teachers selected the phrase *purposeful striving* (Tatina, 1989). For many teachers this misconception of deterministic purposeful striving culminates in evolutionary processes arriving at some predetermined, goal-directed end point (Nehm & Schonfeld, 2007; Tidon & Lewontin, 2004). In a 2004 study of Brazilian secondary teachers, 34% of the participants indicated that evolution always produces improvement (Tidon & Lewontin, 2004). Many teachers mistakenly ascribe evolutionary determinism based on organisms' or populations' needs. This misconception that an organism which needs a particular trait in order to meet its predetermined evolution pinnacle and will, in turn, produce just such a trait via evolutionary processes is pervasive in teacher biological evolution misconception literature (e.g., Crawford et al. 2005; Greene, 1990; Jiménez-Aleijandre, 1994; Nehm & Schonfeld, 2007; Nehm et al. 2009; Rutledge & Warden, 2002). In a 2007 study, more than 25% of the high school science teacher participants indicated that organisms' traits appear when needed (Nehm & Schonfeld, 2007).

Like students, many teachers hold the misconception that characteristics acquired during the lifetime of the organism can be passed along to the next generation (Crawford et al., 2005; Greene, 1990; Jiménez-Aleijandre, 1994; Nehm & Schonfeld, 2007; Rutledge & Warden, 2002; Zuzovsky, 1994). In fact, inheritance of acquired characteristics is one of the most commonly identified biological evolution misconceptions in teachers (Jiménez-Aleijandre, 1994; Zuzovsky, 1994). Closely related to the misconception of acquired characteristics is that of use and disuse. One such example of this type of misconception comes from a participant in a 2005 study involving prospective teachers' ideas about evolution and scientific inquiry. The participant stated: "Lack of use desensitized the gene, turning it off" (Crawford et al. 2005, p. 625). Teacher adherence to the misconception of use and disuse has been documented by numerous researchers (e.g., Crawford et al. 2005; Greene, 1990;

Jiménez-Aleixandre 1992; Nehm & Schonfeld, 2007; Nehm et al. 2009; Zuzovsky, 1994).

Misconceptions of the Nature of Evolution

Studies reveal teachers' biological evolution misconceptions concerning the roles of individuals and populations (e.g., Crawford et al., 2005; Jiménez-Aleijandre, 1994; Nehm & Schonfeld, 2007; Rutledge & Warden, 2002; Tidon & Lewontin, 2004). Common misconceptions involve the evolution of individuals rather than populations (Crawford et al., 2005; Jiménez-Aleijandre, 1994; Rutledge & Warden, 2002; Tidon & Lewontin, 2004) with individuals possibly changing in response to the environment (Jiménez-Aleixandre, 1994; Nehm & Schonfeld, 2007; Rutledge & Warden, 2002). In addition, teachers may subscribe to the misconception that chance cannot be a factor in the origin of complex traits (Nehm & Schonfeld, 2007; Nehm & Sheppard, 2004; Zuzovsky, 1994).

Misconceptions of Mechanisms of Evolution

Teachers hold several misconceptions concerning the mechanisms of biological evolution. Teacher misconceptions about natural selection are persistent and found to be present in a variety of forms (Nadelson, 2009). Gregory (2009) reflects, "It is particularly disconcerting and undoubtedly exacerbating that confusions about natural selection are common even among those responsible for teaching it" (p. 163). Some teachers are even known to view natural selection as independent of biological evolution (Nadelson, 2009). In their study of secondary biology teachers, Moore and Kraemer (2005) found that most participants equated evolution with survival of the fittest. Several researchers also identified this misconception in study participants (e.g., Nadelson, 2009; Tatani, 1989; Zimmerman, 1987).

Teachers are known to possess misconceptions dealing with origination of variation within a population. Such misconceptions may indicate that individuals conform to a specific norm and that variation is abnormal (Greene, 1990; Nehm & Schonfeld, 2007) or that variation is not important to evolution (Jiménez-Aleixandre, 1994; Rutledge & Warden, 2002). In turn, teachers may not understand the role of mutations as they relate to variation (Jiménez-Aleixandre, 1994; Rutledge & Warden, 2002) and may champion the misconception that all mutations are harmful and could not have given rise to new traits (Nehm & Schonfeld, 2007). Teachers may also harbor misconceptions concerning the role of reproduction in evolution (Rutledge & Warden, 2002) such as less desirable traits could not be passed along (Crawford et al., 2005).

Misconceptions of Evidence Supporting Evolution

Although there is little argument among biologists that evolution has and is happening (AAAS, 1989; Moore, 2000; National Association of Biology Teachers, 1997; NAS, 1999; National Research Council, 1985; National Science Teachers Association, 2003; Nelson & Skehan, 2000; Rutledge & Warden, 1999), many teachers doubt the scientific validity of evolutionary theory and state that evolution is not supported by available evidence (Nehm & Schonfeld, 2007; Rutledge & Warden, 2002). In their landmark study of Indiana teachers, Rutledge and Warden (2002) discovered that nearly one-fifth of the 989 participants indicated that evolution was not supported by available evidence. Teachers hold misconceptions concerning biological evolution evidence provided by the fossil record, some volunteering that transitional fossils are absent from the fossil record; that humans and dinosaurs co-existed; and, no fossil species has been found between humans and apes (Nehm & Schonfeld, 2007). Many teachers doubt that humans are the result of evolutionary processes (Rutledge & Warden, 2002); hold to the misconception that humans evolved from monkeys (Lord & Marino, 1993; Sinclair & Pendarvis, 1998); or indicate that humans were created in their present form within the last 10,000 years or so (Berkman et al., 2008).

Origins of Biological Evolution Misconceptions

The scientific community regards evolution as a vital part of science education (NAS, 2008) yet evolutionary theory is one of the most commonly misunderstood areas in biology (Gregory, 2009). It is therefore imperative to identify sources of confusions concerning evolution (Modell, Michael, & Wenderoth, 2005; NRC, 1996; Novak, 2002; Wescott & Cunningham, 2005). Identification of biological evolution-related misconceptions is important because instructional strategies which ultimately might prove effective in combating misconceptions might differ according to the source of the misconception (Abraham, Grzybowski, Renner, & Marek, 1992).

Understanding both students' and teachers' perceptions of the theory of evolution requires an investigation of the variety of factors that might influence the development of such perceptions (Hokayem & BouJaoude, 2008). Much recent research about misconceptions, in general, and in misconceptions of biological evolutionary theory, in specific, deals with the causative agents of these pervasive misconceptions. Research has revealed that sources from which these conceptual difficulties arise are varied and can be complex (Modell, Michael, & Wenderoth, 2005). Sources of biological evolutionary misconceptions have been identified as: (a) From-experience

Misconceptions; (b) Self-constructed Misconceptions (c) Taught-and-Learned Misconceptions; (d) Vernacular Misconceptions; and (e) Religious and Myth-based Misconceptions (Alters & Nelson, 2002).

From-experience Misconceptions

There seems to be a significant disconnect between the nature of the world as reflected in everyday experience and the one revealed by systematic scientific investigation (Shtulman, 2006; Sinatra et al., 2008). Misconceptions have their origins in a diverse set of personal experiences (Wandersee et al., 1994) because personal experience provides the basis for knowledge that is inaccurate (Lawson & Thompson, 1988). From-experience misconceptions are those that individuals surmise either consciously or unconsciously from their everyday experiences (Alters & Nelson, 2002; Gregory, 2009; Sinatra et al., 2008). These types of misconceptions are common because everyday experiences are readily applied to explain seemingly related phenomenon (Driver et al., 1994; Tversky & Kahneman, 1982; Yip, 1998). Wellman and Gelman (1998) describe the conflict between experience-derived misconceptions and scientifically accurate conceptions:

> The experiences that children have with the world further entrench their intuition, and cause them to develop particular ideas about how the world works. Both of the factors make it difficult to adopt new, more scientifically accurate ones. These intuitions provide simple explanations for natural phenomena that work well in everyday life, even if they are not entirely accurate from a scientific standpoint. (as cited in Sinatra et al., 2008)

The origination of many common biological evolution misconceptions can be attributed to from-experience misconceptions. Many of the misconceptions that block an understanding of natural selection develop early is life as part of naïve but practical understandings of how the world is structured (Beardsley, 2004; Evans, 2000; Gregory, 2009; Samarapungavan & Wiers, 1997) and misconceptions concerning spontaneous generation and inheritance of acquired characteristics likewise may have their roots in personal experience (Lawson & Thompson, 1988). Many misconceptions about evolution remain rooted in essentialist thinking (Mayr, 1982, 2001; Sinatra et al., 2008) which is the tendency to believe that things belong to categories because they have an underlying nature that we cannot see, yet that gives things their basic identity (Gelman, 2003). As with many other conceptual biases, the tendency to essentialize seems to arise early in childhood and remains the default for most individuals (Evans, Szymanowski, Smith, & Rosengren, 2005; Gelman, 2004; Shtulman, 2006; Sinatra et al., 2008; Stevens, 2000). The development and retention of misconceptions of situations of chance as applied to biological evolution may be due to an inherent tendency for individuals to interpret chance phenomena in terms of cause and effect (Tversky & Kahneman, 1982; Wolpert, 2007). And, based on experiences, children naturally see the world in terms of teleology (Kelemen, 1999). Children’s ideas about agency and design make it difficult for them to accept the processes of evolution (Bloom, Weisberg, & Skolnick, 2007) and therefore tend to find designed-based accounts of living things more plausible and in keeping with their world view than an evolutionary account (Evans, 2000, 2001, 2008; Sinatra et al., 2008).

Self-constructed Misconceptions

Self-constructed misconceptions occur when information that individuals assimilate produces disequilibration with what they already *know* and they accommodate the new knowledge in the framework of an old misconception (Alters & Nelson, 2002). When individuals are confronted with a new or surprising situation, they rely on some basic assumptions to simplify and to find a workable explanation. If the new data does not fit their assumptions, they make errors and arrive at misconceptions because many of these situations are unnatural and unintuitive (Bloom et al., 2007; Sinatra et al., 2008). Therefore, both adults and children resist acquiring scientific information that clashes with commonsense intuitions about the physical and psychological domains (Bloom et al., 2007). Mintzes and Wandersee (1998) cited the importance of student prior knowledge as an impediment to learning: "The single most important factor influencing learning is what the learner already knows" (p. 81, as cited in Morrison & Lederman, 2003). Gould (2002) argued that there are significant levels of prior knowledge required for comprehending the relationship between uncertainty and evolution (as cited in Nadelson, 2009). The problem with teaching science to children then is not what the student lacks, but rather what the student possesses in terms of misconceptions already in place for understanding the phenomena (Carey, 2000). Cobern (1996) indicated that it is not surprising to see some students fail to develop accurate scientific conceptions even after carefully designed instruction due to the interference of other components of their worldview (as cited in Deniz et al., 2008). Several educators have proposed that the concept of evolution is such an abstract topic that high school students, most of whom still think at the concrete level, cannot be realistically expected to construct solid understandings of the topic (Halldén, 1988; Keown, 1988; Lawson & Thompson, 1988; Shayer, 1974).

Natural selection usually competes unsuccessfully with intuitive ideas about inheritance, variation, function, intentionality, and probability (Gregory, 2009). Individuals who have a long-held impression that evolution is predictably progressive, with the end goal being humans, will incorporate natural selection into that type of determinism (Alters & Nelson, 2002). Until an individual has risen above the concrete level, he or she will be unlikely to adequately comprehend evolution as explained by natural selection (Lawson & Thompson, 1988).

Taught-and-learned Misconceptions

Taught-and-learned misconceptions are misconceptions that have been taught by parents, teachers, and others or unconsciously learned from fiction (Alters & Nelson, 2002). These misconceptions are reinforced by the popular media, textbooks, and other sources, attempting to simplify concepts (Bishop & Anderson, 1990; Losh, Tavani, Njorge, Wilke & McAuley, 2003; Modell, Michael, & Wenderoth, 2005; Morrison & Lederman, 2003; Storey, 1991; Wandersee et al., 1994).

Several science education researchers have reported that textbooks are used as the primary source of information in the science classroom (Harms & Yager, 1981; Stake & Easley, 1978; Yore & Denning, 1989) and it is therefore not surprising then that important sources of taught-and-learned misconceptions are textbooks themselves (Rees, 2007; Storey, 1991; Wandersee et al., 1994). In the subject area of biology, biology teachers rely heavily on textbooks for use in their instruction (Yager, 1982) especially when they are novices or teaching outside their expertise (Ball &

Feiman-Nemser, 1988). Biology textbooks therefore strongly influence which topics are covered by biology teachers (Barber & Tomera, 1985; Skoog, 1984). For example, both student and teacher understanding of Darwin's contribution to biology inevitably comes largely from school and college textbooks (Rees, 2007). In many cases it is possible that the very textbooks instructors use to help correct student misconceptions about evolution contribute to the problem as several studies have systematically identified misconceptions in biology widely-used textbooks (Barrass, 1984; Rees, 2007; Soyibo, 1987).

A study of 50 major college-level textbooks in the fields of evolution, biology, ecology, genetics, paleontology, and systematics yielded disappointing results in even the baseline definition of evolution. Overall, the researcher concluded that many textbooks do not present evolution concepts accurately (Linhart, 1997). Over a period of many years textbooks for Advanced Level Biology have contained misconceptions and inaccuracies relating to Darwin's theory of evolution and the history of its development (Rees, 2007). Textbooks likewise exacerbate students' difficulties understanding biology's broader themes by overemphasizing technical terminology at the expense of providing meaningful narratives that allow students to weave key ideas into a coherent and sensible framework (Koppal & Caldwell, 2004). Successive generations of texts have perpetuated misconceptions about biological evolution as textbooks inevitably copy each other's mistakes (Rees, 2007, p. 55).

In instructor-centered teaching, the instructor determines, primarily from tradition and disciplinary content, exactly what is to be taught and how it should be taught (Alters & Nelson, 2002). A number of studies reveal that many teachers, including those with experience, possess misconceptions about various biological concepts (e.g., Affanato, 1986; Bishop & Anderson, 1990; Brumby, 1984; Chinsamy & Plaganyi, 2007; Clough & Wood-Robinson, 1985; Demastes, Good et al., 1995; Greene, 1990; Nehm & Schonfeld, 2007; Osif, 1997; Settlage, 1994; Yip, 1998). This suggests that teachers may critically impede student conceptual development of scientific explanations (Crawford et. al., 2005; Fisher, 2004; Jarvis, Pell, & McKeon, 2003; Kikas, 2004; Simpson & Marek, 1988) and convey such misconceptions to their students through inaccurate teaching (Alters & Nelson, 2002; Barrass, 1984; Driver et al., 1994; Fisher, 2004; Haidar, 1997; Jarvis et al., 2003; Lawrenz, 1986; Mohapatra & Bhattacharyya, 1989; Sanders, 1993; Wandersee et al., 1994; Yip, 1998). Evidence therefore indicates that there is great potential for teachers' misconceptions about biological evolution to be taught to students (Fisher, 2004; Wood-Robinson, 1994). In addition, biological evolution misconceptions are perpetuated from generation to generation as teachers' understanding of content is nearly directly correlated with their own education (Hoy, Davis, & Pape, 2006; Parjares, 1992) and most teachers teach as they were taught (Alters & Nelson, 2002; Deemer, 2004; Llinares & Krainer, 2006; Tobin, Tippins & Gallard, 1994).

Cobern (1994) stated: "Nowhere in science is the overlap between scientific ideas and other ideas in society more clear than with the theory of evolution" (p. 584). Consequently, such overlap of ideas is expected to be carried to the classroom because students and teachers are influenced by their cultures and society (Hokayem & BouJaoude, 2008) which in turn can affect student understanding of evolutionary theory (Allchin, 2007; Almquist & Cronin, 1988; Hokayem & BouJaoude, 2008; Sinclair, Pendarvis & Baldwin, 1997). One pervasive source of cultural misconceptions of biological evolution is the media. Media stories about evolution typically are sensational stories that deal with the negative impacts of evolution, such as relation to crime, addiction, or disease (Brem et al., 2003). This exposure has most likely helped form ideas and beliefs about evolution prior to formal biology instruction (Woods & Scharmann, 2001). For example, many have repeatedly seen dinosaurs and humans coexisting in print and visual materials such as films, books and cartoons (Alters & Alters, 2001; Alters & Nelson, 2002). Parents also can contribute to biological evolution misconceptions as parental views of evolutionary theory are necessarily a part of students' family cultural backgrounds (Deniz et al., 2008).

Vernacular Misconceptions

Formation of some misconceptions can be attributed to language usage (Jacobs, 1989; Lawson & Thompson, 1988; Veiga, Costa Pereira, & Maskill, 1989; Yip, 1998). Vernacular misconceptions arise from the difference between the scientific use of a word and its everyday use, and the consequent misunderstanding of the distinction (Alters & Nelson, 2002). Gregory (2009) notes, "The tendency, both outside and within academic settings, to use inaccurate language to describe evolutionary phenomena probably serves to reinforce these problems [misconceptions]" (p. 172). While expert biologists easily recognize the shift from one frame of reference to another, novices may not, thus creating persistent misconceptions (Moore et al., 2002). An example of a common vernacular misconception is evolution's status of being *only* a theory (Alters & Nelson, 2002; Ayala, 2000; Greenwood & North, 1999; Hemenway, 1999; Johnson & Peeples, 1987; McComas, 1998; Miller, 2008; Nadelson, 2009). Lack of understanding about evolutionary theory is frequently associated with misconceptions of evolution (Alters & Alters, 2001; McComas, 1998; Miller, 1999, 2008) to the point that individuals may believe evolutionary theory is equivalent to speculation (Blackwell, Powell, & Dukes, 2003). In addition, terms such as design, need, adapt, adaptation, fitness, competition, population, evidence, law, and hypothesis have both an everyday and a scientific meaning which likewise can lead to vernacular misconceptions (Alters & Nelson, 2002; Bishop & Anderson, 1990; Bizzo, 1994; Dagher & BouJaoude, 1997; Sinatra et al., 2008). Bizzo (1994) suggests that the theory of evolution is socially reconceptualized in the sense that concepts such as competition and adaption may not reach the students in the contexts of biological evolution, but rather in a sense that conveys violence and destruction (Hokayem & BouJaoude, 2008). This socially reconceptualized figurative language contrasts with the more precise scientific language of concrete specificity, which is less prone to figurative license (Tidon & Lewontin, 2004). Gregory (2009) warns that such linguistic shortcuts may foster origination of misconceptions.

Religious and Myth-Based Misconceptions

Religious and myth-based misconceptions are concepts in religious and mythical teachings that when transferred into science education become factually inaccurate (Alters & Nelson, 2002). Considered to be subjective ways of knowing, beliefs have been shown to interfere with the ability to objectively view scientific evidence (Sinclair et al., 1997) and may potentially blur the line between scientific knowledge and religion (Sinatra, Southerland, McConaughy, & Demastes, 2003). Although religious beliefs themselves cannot be treated as misconceptions (Hokayem & BouJaoude, 2008), research has shown that religious beliefs may negatively affect understanding of the nature of science and the theory of evolution and therefore serve as sources of misconceptions (Nehm & Sheppard, 2004; Trani, 2004). Both students and members of the general public often experience apparent conflicts between religious beliefs versus evolutionary theory (Ayala, 2000; Goldsmith, 2000; Johnson & Peeples, 1987; Moore, 2000; Sinclair et al., 1997). For example, unlike most other concepts in science, student understanding of evolution and much geology appears to be markedly affected by religious beliefs (Alters & Nelson, 2002).

In summary this literature indicates quite clearly that misconceptions of biological evolution are associated with numerous aspects of biological evolutionary theory. The literature has shown these misconceptions to be pervasive and persistent in both students and teachers alike. In addition, this review emphasizes that misconceptions of biological evolution can and do originate from many and varied sources including teacher transmission to student.

Chapter III

Research Methodology

This study is designed to identify the role of the secondary school life science teacher in student acquisition of biological evolution-related misconceptions. This study is relevant because evidence exists indicating that many science misconceptions may actually have been taught by teachers to their students (Alters & Nelson, 2002; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Fisher, 2004), yet little formal research has actively addressed secondary school life science teacher contributions to student acquisition of biological evolution-related misconceptions. This chapter identifies and describes the methodology of the current study.

The General Perspective

The research perspective to be utilized in this study is quantitative in nature. The quantitative perspective derives from a positivist epistemology which holds that there is an objective reality that can be expressed numerically. As a consequence, the quantitative perspective emphasizes not only measurements but the search for relationships (Glatthorn & Joyner, 2005).

In the search for relationships between secondary school life science teachers' biological evolution-related misconceptions and such misconceptions held by their students, two quantitative research types will be employed. Initially descriptive research, used to describe the characteristics of a population by directly examining samples of that population (Glatthorn & Joyner, 2005), will identify the prevalence and categories of biological evolution-related misconceptions possessed by a sample of secondary school life science teachers. Descriptive research will also identify the prevalence and categories of biological evolution-related misconceptions adhered to in a sample of students both prior to and following instruction in biological evolution curriculum.

Additionally, correlational research, which attempts to understand patterns of relationships among variables (Glatthorn & Joyner, 2005), will be engaged with two goals in mind. Initially, correlation research will analyze the relationship between student prevalence and categories of biological evolution-related misconceptions prior to and following instruction in biological evolution curriculum. Second, correlational research will be used to analyze the relationship between teacher and student prevalence and categories of biological evolution-related misconceptions prior to and following student instruction in biological evolution curriculum. Although multiple statistical analysis tools will be utilized throughout the research process, the basic correlational research subtype to be employed in this study is bivariant correlation. Bivariant correlation describes methods for directly determining the relationship among two variables and will be used in inferential testing as well as in the production of descriptive statistics (Lomax, 2007).

The Research Context

This study will take place in a Southern state which has 484 high schools (Oklahoma Secondary Schools Activities Association [OSSAA] 2010). Participating high schools will serve as study sites. For the purposes of this study, a high school is defined as a secondary school possessing any combination of grades 9 through 12. Participating high schools will contain the study’s two units of analysis: secondary school life science teachers who will teach at least one section of Biology I during the

2010-2011 academic year, and their respective Biology I students in a single section of the Biology I course.

Data for the 2009-2010 academic year identify a total of 654,511 students enrolled in the study state's public education system (Oklahoma State Department of Education [OSDE] 2009a). Student ethnicity distribution within the student population is currently 19% American Indian/Alaskan, 2% Asian/Pacific Islander, 11% Black/Non-Hispanic, 11% Hispanic, and 56% White Non-Hispanic/Other (figures were rounded in the document so they do not total 100%), (OSDE, 2009a). Each of the 484 public high schools will be classified based on average daily membership (ADM) and institutional affiliation, using information provided by the state's department of education. In order to ensure confidentiality, a numerical code will be used to identify each participating high school.

Descriptive data of the participating high schools to be identified include general nature of the community (urban, suburban, rural), grade levels, student enrollment and student demographics. In addition, descriptive data of each secondary school's Biology I program will be identified. These data will include the number of secondary school life science teachers teaching the Biology I sections, the time frame in which the Biology I course is offered, and the number of sections of Biology I taught during the academic year. Research data collection activities will cover a time period of approximately 14 months, commencing in April 2010 and ceasing in May 2011.

The Research Participants

Two target populations will be identified in this study. These target populations consist of secondary school life science teachers employed at the identified 484 high schools within the study area and those students enrolled in a selected life science course taught by these teacher subjects. Selection of life science teacher subjects for this study will be based on multiple criteria. First, teacher subjects must be employed by one of the high schools within the study area either on a full-time or part-time basis. Second, although biology or biology education may not be the teacher subjects' undergraduate or graduate major, nor life science courses the teachers' primary teaching responsibility, teacher subjects must possess state teaching certification in the biological sciences and teach at least one Biology I course section at the high school level (typically 9th or 10th grade) during the 2010-2011 academic year. A further requirement for inclusion of a teacher subject into the study requires that students from one section of the teacher subject's Biology I course be recruited by that teacher to serve as student subjects for the duration of the study.

Each potential teacher subject who meets the above criteria and chooses to participate in the study will be presented with an *Informed Consent to Participate in a Research Study* form (see Appendix A) approved by the researcher's university Internal Review Board (IRB). This document identifies the purpose of the study, procedures used in the study, length of participation, the voluntary nature and confidentiality of the study, the study's potential benefits and risks, and researcher contact information. Once a signature has been secured on the informed consent document, individuals then become teacher subjects in the study.

In order to reduce subject bias, the primary purpose of the study, which is to identify the teacher's role in student acquisition of biological evolution-related misconceptions, will not be presented during the recruitment phase, informed consent phase, nor during the study itself. Potential teacher subjects will be informed that the study's purpose involves the identification of levels of biological evolution literacy in teacher subjects as well as student subjects both prior to and following instruction in biological evolution curriculum.

The second study population includes student subjects. Student subjects will be recruited concurrently with teacher subjects. Criteria for the selection of student subjects include first time enrollment in a Biology I course section taught by one of the study's teacher subjects during the 2010-2011 academic year. The researcher's university IRB does not require informed consent of student subjects in this study because the study's teacher subjects will administer both pre- and post-instruction questionnaires to the student subjects as part of the teachers' regular classroom instruction and the researcher will not interact with any students who completes the questionnaires. In addition, student subjects will remain anonymous throughout the study and the researcher will only receive the anonymous questionnaire responses as existing data. Individual student subjects' pre- and post-instruction surveys will be matched based on responses to the following three questions asked of the students on each of the two surveys: a) When is your birthday?; b) How many brothers do you have?; c) How many sisters do you have? Once teacher subjects administer the pre-instruction questionnaires to students in a Biology I course section, those students then become student subjects in the study.

Selection of the Sample

The study's teacher subject sample will be solicited via mail from the population of secondary school life science teachers who teach at least one Biology I course section during the 2010 – 2011 academic year in one of the study site's identified 484 high schools. The study's student sample will be those participating teacher subjects' students enrolled in one Biology I course section during the 2010 – 2011 academic year. In order to reduce the incidence of participant bias and acquire an accurate cross-sectional representation of both the study area's teacher and student populations, only one teacher subject and associated student subjects will be recruited from each high school study site.

Because of the range of diversity regarding student and teacher populations and demographics among the 484 high schools where Biology I is taught, ensuring broad representation of all high school sites within the study area is important. Currently the most logical and practical classification of high schools within the study area is the *2009-2010 Average Daily Membership for Classification Purposes* document, produced by the OSSAA (2010). Average daily membership for the 484 high schools ranges from a high of 4,461.85 students in a large metropolitan high school to a low of 14.85 students in a small rural high school (OSSAA, 2010). The diversity found within the 484 high schools seems appropriate for this study.

In order to establish a 95% confidence level with a 5% confidence interval, a minimum of 214 of the total 484 high schools will be needed to serve as sites for the study (Creative Research Systems, 2010). These potential 214 participating high schools represent 44.21 percent of the total number of 484 high schools in the study area. As mail solicitation survey return rates are frequently below 50% (Rogelberg & Luong, 1998), in order to maintain a high confidence level and a low confidence interval, teacher subjects and associated student subjects from all 484 high schools will be solicited for participation in this study.

Instruments Used in Data Collection

Purpose and rational.

The *Biological Evolution Literacy Survey* (BEL) instrument (see Appendices B-D) will be the primary research tool used for data collection in this study. A survey design provides a quantitative description of some fraction of the population through the data collection process of asking questions of people (Fowler, 1988, as cited in Creswell, 1994). The subset of the population which provides survey data for subsequent analysis is known as the sample (Nardi, 2006). The purpose of survey research is to generalize from a sample to a population so that inferences can be made about some characteristic, attitude, or behavior of this population (Babbie, 1990).

For this study, attempting to identify the role of the secondary school life science teacher in student acquisition of biological evolution-related misconceptions, the survey is the preferred data collection instrument. In this study, the BEL survey instrument will be administered to identify and classify biological evolution-related misconceptions held by secondary school life science teacher subjects (see Appendix B). In addition, biological evolution-related misconceptions possessed by these teacher subjects' life science students will be identified and classified by means of a survey instrument both prior to and following instruction in biological evolution curriculum (see Appendices C and D).

Each method for collecting data has advantages and disadvantages that should be evaluated before deciding which to use for a particular research problem. The following survey characteristics identify why the survey instrument is the preferred means of data collection for this study: (a) surveys are suitable for probability sampling and accurate generalization (Creswell, 1994; Fowler, 1988; Nardi, 2006); (b) a single survey can address multiple topics (Babbie, 1990); (c) survey instruments are well suited for personal and sensitive topics, such as evolution (Nardi, 2006; Rubin & Babbie, 2010); (d) surveys are ideal for asking about opinions and attitudes (Nardi, 2006); (e) studies using survey instruments are easily compared when they possess similar questions (Nardi, 2006); (f) the use of the survey instrument makes it easy to replicate a study (Babbie, 1990; Nardi, 2006); (g) surveys use standardized questions and allow for easy coding of closed-ended items (Nardi, 2006); and (h) surveys are less costly to reach larger samples and are less labor intensive to collect data when compared to many other research methods (Babbie, 1990; Creswell, 1994; Nardi, 2006). The survey method possesses several advantages to the research subject as well in that surveys can guarantee anonymity if required (Nardi, 2006; Rubin & Babbie, 2010) and allow subjects to answer at their own pace (Nardi, 2006).

Survey design.

Based on this study's research questions, the survey design will follow two forms. Initially, secondary school life science teacher subjects (TS) will be surveyed within a cross-sectional survey design. A cross-sectional survey design dictates that data are collected at a single point in time from a sample selected to describe some larger population at the time (Babbie, 1990; Nardi, 2006). Such a survey design can be used for descriptive purposes as well as for determination of relationships between variables at the time of the study (Babbie, 1990). TS will be surveyed immediately on acceptance into the study.

The study's student subjects (SS) will be surveyed within a longitudinal survey design. A longitudinal survey design entails that survey data are collected at different points in time from a sample selected to describe some larger population at the time and changes in descriptions and explanations are recorded and analyzed (Babbie, 1990). The specific type of longitudinal survey design to be used in this study is a panel study. A longitudinal panel study involves following the same subjects and surveying them at different points in time (Nardi, 2006). SS will initially be surveyed during the first week of the 2010-2011 academic year and will be subsequently surveyed immediately following the completion of biological evolution curriculum instruction or near the completion of the Biology I course in which they are enrolled.

Instrument development.

Three survey instruments will be used in this study, a *Teacher Questionnaire* (TQ) (see Appendix B), a *Pre-instruction Student Questionnaire* (PSQ) (see Appendix C), and a *Post-instruction Student Questionnaire* (POSQ) (see Appendix D). Questionnaires used in this study were developed after an extensive review of literature related to biological evolution-related misconceptions held by both teachers and students (see *Literature Review* section). The designs of the three questionnaires follow recommendations proposed by individuals who have written extensively on the topic (Babbie, 1990; Fink & Kosecoff, 1998; Leedy & Ormrod, 2001; Nardi, 2006; Salant & Dillman, 1994).

The TQ is divided into two components, the initial *Biological Evolution Concepts* section and subsequent *Instructor and Course Information* section. The first section of the TQ uses a Likert rating scale to collect data concerning biological evolution-related misconceptions held by TS. The scale provides five numbered responses which include:

1. Strongly agree
2. Agree
3. Somewhat disagree
4. Strongly disagree
5. Undecided/never heard of it

This section of the TQ contains 25 biological evolution misconception-related statements to which TS will respond. Table 1 identifies literature sources of biological evolution-related misconceptions which support the selection of each of these statements for this study (complete source information is presented in the reference section). These 25 statements are grouped into five categories of biological evolution-related misconceptions. These five categories were produced by generalizing the exhaustive list of misconceptions referenced throughout the literature.

Table 1.

Literature Sources of Biological Evolution Misconceptions

Source	**Nature of science**	**Dating Methods**	**2nd Law of thermodynamics**	**Time and age of the Earth**	**Theory of evolution**	**Evolution purposefulness**	**Evolution related to need**	**Inheritance of acquired traits**	**Inheritance of selected traits**	**Individuals versus population**	**Random production of new traits**	**Environment role in trait appearance**	**Adaptation**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
AAAS, 1993										X		X	
Abraham et al, 2009							X			X	X		X
Alters & Alters, 2001	X	X	X	X									
Alters & Nelson, 2002						X	X	X			X		
Anderson et al., 2002							X	X		X	X	X	
Banet & Ayuso, 2003							X	X					
Beardsley, 2004			X		X			X					
Berkman et al., 2008				X									
Berra, 1990			X		X			X					
Bishop & Anderson, 1986													X
Bishop & Anderson, 1990					X	X	X	X	X			X	X
Bizzo, 1994					X	X							X
Brumby, 1979					X			X					
Brumby, 1984					X	X	X						
Bybee, 2001					X								
Clough Wood-Robinson, 1985					X		X						
Crawford et al., 2005							X	X		X			X
Creedy, 1993					X								
Dagher & BouJaoude, 1997	X					X		X					X
Deadman & Kelly, 1978					X	X		X					
Demastes, Good, & Peebles, 1995						X							
Driver et al., 1994										X		X	
Ferrari & Chi, 1998					X	X		X					
Futuyama, 1995			X										
Geraedts & Boersma, 2006					X			X					
Greene, 1990					X		X	X					X

Table 1 (continued).

Source	Nature of science	Dating Methods	2nd Law of thermodynamics	Time and age of the Earth	Theory of evolution	Evolution purposefulness	Evolution related to need	Inheritance of acquired traits	Inheritance of selected traits	Individuals versus population	Random production of new traits	Environment role in trait appearance	Adaptation
	1	2	3	4	5	6	7	8	9	10	11	12	13
Gregory, 2009					X	X	X	X			X	X	
Isaak, 2003													
Jensen & Finley, 1995					X								
Jensen & Finley, 1996					X	X		X					
Jiménez-Aleixandre, 1992								X				X	X
Jiménez-Aleixandre, 1994							X	X		X			
Jiménez-Aleixandre & Fernández-Perez, 1987					X			X					
Jungwirth, 1977						X							
Kampourakis & Zogza, 2007					X	X	X						
Kampourakis & Zogza, 2008					X	X							
Kampourakis & Zogza, 2009					X	X							
Kelemen & Rosset, 2009						X							
Lord & Marino, 1993						X							
Mayr, 1982							X	X	X				
Moore, 2002													X
Moore & Kraemer, 2005	X				X								
Moore et al., 2002					X	X							
Nadelson, 2009	X				X								
Nehm & Reilly, 2007					X	X							
Nehm & Schonfeld, 2007	X				X	X	X	X		X			X
Nehm & Sheppard, 2004													
Nehm et al., 2009							X						X
Nelson, 2008													
Passmore & Stewart, 2002						X	X	X					
Pedersen & Halldén, 1992					X								X

Table 1 (continued).

Source	Nature of science	Dating Methods	2^{nd} Law of thermodynamics	Time and age of the Earth	Theory of evolution	Evolution purposefulness	Evolution related to need	Inheritance of acquired traits	Inheritance of selected traits	Individuals versus population	Random production of new traits	Environment role in trait appearance	Adaptation
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Prinou, Halkia, & Skordoulis, 2008				X	X	X							
Robbins & Roy, 2007				X	X			X		X			
Rudolph & Stewart, 1989	X												
Rutledge & Warden, 2002	X			X			X		X			X	
Samarapungavan & Wiers, 1997						X	X						
Scott, 2004	X	X	X	X									X
Settlage, 1994						X	X						
Shtulman, 2006					X								
Sinatra, Brem, & Evans, 2008		X	X		X								X
Sinclair & Pendarvis, 1998													
Smith & Sullivan, 2007			X	X		X							X
Southerland et al., 2001						X							X
Spindler & Doherty, 2009					X								
Stern & Ben-Akiva, 2007								X		X			
Tamir & Zohar, 1991					X	X							X
Tatina, 1989						X							
Tidon & Lewontin, 2004						X				X			
Zimmerman, 1987													
Zuzovsky, 1994								X					X

Table 1 (continued).

Source	Randomness of evolution	Environment role in trait survival	Variation	Survival of fittest	Role of population size	Evolution of complex structures	Inheritance of beneficial traits	Evidence supporting evolution	Human evolution	Human coexistence with dinosaurs	Scientists' views of evolution	Scientists' views of evolution
	14	15	16	17	18	19	20	21	22	23	24	25
AAAS, 1993	X		X		X		X					
Abraham et al, 2009										X		X
Alters & Alters, 2001												
Alters & Nelson, 2002			X							X		
Anderson et al., 2002			X	X			X					
Banet & Ayuso, 2003												
Beardsley, 2004												
Berkman et al., 2008									X			
Berra, 1990												
Bishop & Anderson, 1986												
Bishop & Anderson, 1990			X	X								
Bizzo, 1994												
Brumby, 1979							X					
Brumby, 1984												
Bybee, 2001												
Clough Wood-Robinson, 1985												
Crawford et al., 2005					X		X					
Creedy, 1993									X			
Dagher & BouJaoude, 1997												
Deadman & Kelly, 1978												
Demastes, Good, & Peebles, 1995												
Driver et al., 1994	X		X		X							
Ferrari & Chi, 1998												
Futuyama, 1995												
Geraedts & Boersma, 2006												
Greene, 1990			X									

Table 1 (continued).

Source	Randomness of evolution	Environment role in trait survival	Variation	Survival of fittest	Role of population size	Evolution of complex structures	Inheritance of beneficial traits	Evidence supporting evolution	Human evolution	Human coexistence with dinosaurs	Scientists' views of evolution	Scientists' views of evolution
	14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Gregory, 2009			X				X					
Isaak, 2003	X											
Jensen & Finley, 1995												
Jensen & Finley, 1996												
Jiménez-Aleixandre, 1992												
Jiménez-Aleixandre, 1994	X	X		X								
Jiménez-Aleixandre & Fernández-Perez, 1987												
Jungwirth, 1977												
Kampourakis & Zogza, 2007												
Kampourakis & Zogza, 2008												
Kampourakis & Zogza, 2009												
Kelemen & Rosset, 2009												
Lord & Marino, 1993									X			
Mayr, 1982			X									
Moore, 2002												
Moore & Kraemer, 2005				X								
Moore et al., 2002												
Nadelson, 2009				X								
Nehm & Reilly, 2007				X			X					
Nehm & Schonfeld, 2007		X	X		X	X		X	X	X	X	X
Nehm & Sheppard, 2004						X						
Nehm et al., 2009												
Nelson, 2008						X		X				
Passmore & Stewart, 2002												
Pedersen & Halldén, 1992												

Table 1 (continued).

Source	Randomness of evolution	Environment role in trait survival	Variation	Survival of fittest	Role of population size	Evolution of complex structures	Inheritance of beneficial traits	Evidence supporting evolution	Human evolution	Human coexistence with dinosaurs	Scientists' views of evolution	Scientists' views of evolution
	14	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Prinou, Halkia, & Skordoulis, 2008												
Robbins & Roy, 2007				X					X			
Rudolph & Stewart, 1989												
Rutledge & Warden, 2002		X	X		X		X	X	X		X	
Samarapungavan & Wiers, 1997												
Scott, 2004												
Settlage, 1994							X					
Shtulman, 2006												
Sinatra, Brem, & Evans, 2008												
Sinclair & Pendarvis, 1998									X			
Smith & Sullivan, 2007				X					X			X
Southerland et al., 2001												
Spindler & Doherty, 2009												
Stern & Ben-Akiva, 2007												
Tamir & Zohar, 1991												
Tatina, 1989				X								
Tidon & Lewontin, 2004					X							
Zimmerman, 1987				X								
Zuzovsky, 1994						X						

The following classes of biological evolution-related misconception data will be collected on the TQ Biological Evolution Concepts component:

1. Misconceptions of science, scientific methodology and terminology
2. Misconceptions of the intentionality of evolution
3. Misconceptions of the nature of evolution
4. Misconceptions of the mechanisms of evolution
5. Misconceptions of evidence supporting evolution

The items representing each of the five classes of biological evolution-related misconceptions are identified in Table 2.

Table 2

Description of Scale Items Used in Part I of Teacher and Student Questionnaires

Item Number	Item Content	Misconception Class
1.	A scientific theory that explains a natural phenomenon is defined as a “best guess’ or “hunch”.	SSMT
2.	The scientific methods used to determine the age of fossils and the earth are reliable.	SSMT
3.	According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms.	SSMT
4.	The earth is old enough for evolution to have occurred.	SSMT
5.	Evolution cannot be considered a reliable explanation because evolution is only a theory.	SSMT
6.	Evolution always results in improvements.	IE
7.	Members of a species evolve because of an inner need to change.	IE
8.	Traits acquired during the lifetime of an organism (for example, large muscles produced by body building) will not be passed along to offspring.	IE
9.	If evolution selects for webbed feet, all individuals in the next generation will have more webbing on their feet than do individuals in their parents’ generation.	IE
10.	Evolution cannot cause an organism’s traits to change within its lifetime.	IE
11.	New traits within a population appear at random.	NE
12.	The environment determines which traits appear in a population.	NE
13.	By means of evolution, individual organisms adapt to their environments.	NE
14.	Evolution is a totally random process	NE
15.	The environment determines which traits are best suited for survival	NE

Table 2 (continued).

Item Number	Item Content	Misconception Class
16.	Variation among individuals within a species is important for evolution to occur.	ME
17.	"Survival of the fittest" means basically that "only the strong survive."	ME
18.	The size of the population has no effect on the evolution of a species.	ME
19.	Complex structures such as the eye could have been formed by evolution.	ME
20.	Only beneficial traits are passed on from parent to offspring.	ME
21.	There exists a large amount of evidence supporting the theory of evolution.	ESE
22.	According to the theory of evolution, humans evolved from monkeys, gorillas, or apes.	ESE
23.	Scientific evidence indicates that dinosaurs and humans lived at the same time in the past.	ESE
24.	The majority of scientists favor evolution over other explanations for life's diversity.	ESE
25.	Transitional fossils which represent intermediate forms between species are rare.	ESE

Note. SSTM = Science, Scientific Methodology and Terminology; *IE* = Intentionality of Evolution; *NE* = Nature of Evolution; *ME* = Mechanisms of Evolution; *ESE* = Evidence Supporting Evolution.

The second section of the TQ instrument will be used to collect data related to the teacher and Biology I course assignment. This section is based on components discovered in similar questionnaires dealing with general education data collection (McWilliams, 2002; Nardi, 2006). The following types of data will be collected from the Instructor and Course Information component of the TQ:

1. Gender
2. Teacher education level
3. Teacher degree major
4. Emphasis given to evolution education during teacher's college education
5. Years of teaching experience
6. Teacher biology certification status
7. Teacher employment status
8. Teacher primary teaching duty
9. Number of Biology I course sections the teacher has taught throughout their career
10. Number of hours teacher devotes to teaching evolution concepts in a Biology I course section
11. Teacher self-rating of evolution knowledge
12. Teacher emphasis placed on specific biological evolution concepts as required by the National Science Education Standards (National Research Council [NRC], 1996) document (see Appendix E) and the Priority Academic Student Skills (OSDE, 2009b) document (see Appendix F)
13. Number of Biology I course sections taught at study site

14. Number of different teachers teaching at least one section of the Biology I course
15. Time frame for teaching the Biology I course.

The PSQ (see Appendix C) is also divided into two sections, the *Biological Evolution Concepts* and *Student Information* sections. The initial Biological Evolution Concepts section of the student questionnaire duplicates that of the Biological Evolution Concepts section of the TQ (see Appendix B), using the identical Likert rating scale to collect data concerning biological evolution-related misconceptions held by secondary students enrolled in a Biology I course section prior to instruction in biological evolution curriculum. As with the Biological Evolution Concepts section of the TQ*,* the following classes of biological evolution-related data will be collected using the Biological Evolution Concepts section of the PSQ:

1. Misconceptions of science, scientific methodology and terminology
2. Misconceptions of the intentionality of evolution
3. Misconceptions of the nature of evolution
4. Misconceptions of the mechanisms of evolution
5. Misconceptions of evidence supporting evolution

The items representing each of the five classes of biological evolution-related misconceptions are identified in Table 2.

The Student Information section of the PSQ (see Appendix C) will be used to collect data related to the student subjects. This section is based on components discovered in similar questionnaires dealing with general education data collection (Cunningham & Wescott, 2009; Nardi, 2006). The following types of data will be collected from the Student Information section of the Pre-instruction Student Questionnaire:

1. Student gender
2. Student ethnicity
3. Student classification
4. Identification of previous enrollment in a Biology I course
5. Student self-rating of evolution knowledge
6. Student questionnaire coding information which includes:
    a. Birthday
    b. Number of brothers
    c. Number of sisters

The second questionnaire to be administered to student subjects is the POSQ (see Appendix D). The POSQ possesses both a Biological Evolution Concepts section and a Student Information section. These two sections are identical to sections contained in the PSQ (see Appendix C). The student questionnaire coding information and redundant questions required in the Student Information section of the POSQ will be used to assist in correlation of individual student subjects' pre- and post-instruction student questionnaires.

The survey instrument used in this study was adapted with permission (see Appendix G) from Cunningham and Wescott (2009) who, in turn, adapted their survey instrument from Almquist and Cronin (1988) with additions from Wilson (2001), and Bishop and Anderson (1986, 1990). The initial survey produced by Almquist and Cronin attempted to identify students' basic knowledge about the processes of evolution and their opinions on issues pertaining to science and religion. The purpose of Cunningham and Wescott's 2009 study was to assess how students' opinions and understanding of evolutionary theory may have changed in the interim since the 1988 Almquist and Cronin study.

The Cunningham and Wescott (2009) instrument on which this study's instrument is based contains 24 statements classified into the following four categories: a) evolutionary theory; b) scientific facts; c) process of evolution; and d) language of science. For this present study, Cunningham and Wescott's four-category classification was modified into five categories of biological evolution-related misconceptions that are commonly employed in the literature (e.g., Alters & Alters, 2001; Bishop & Anderson, 1990; Greene, 1990; Gregory, 2009; Jensen & Finley, 1996; Wandersee et al., 1994; Wescott & Cunningham 2005; Wilson, 2001). These categories include: a) misconceptions of science, scientific methodology and terminology; b) misconceptions of the intentionality of evolution; c) misconceptions of the nature of evolution; d) misconceptions of the mechanisms of evolution; and e) misconceptions of evidence supporting evolution.

Five statements were identified or developed for each of the five categories of biological evolution-related misconceptions and included in the present study's instrument (see Table 2). Sixteen of the 24 statements included in Cunningham and Wescott's (2009) study served as the basis for sixteen of the twenty-five statements included in this study. These statements were used in their original form, modified, or served as inspiration for the development of related statements. The additional nine statements used in this study were developed based on common biological evolution-related misconceptions cited in the literature (See Table 1).

The internal reliability of the Cunningham and Wescott's (2009) survey instrument was investigated using Cronbach's alpha, which was obtained using the alpha option of PROC COOR in SAS (SAS Institute Inc. 2002). Cronbach's alpha quantifies how effectively a set of questions measures latent themes. The alpha coefficients range from 0 to 1, and values of 0.7 or above are accepted as reliable (Nunnaly, 1978). Cunningham and Wescott identified a Cronbach's alpha of 0.75 for their 24-statement questionnaire which indicates that the internal reliability of the questionnaire is acceptable. Additionally Cunningham and Wescott noted that the reliability coefficient does not decrease by more than 0.01 if any item is deleted, indicating that removing any item would not greatly decrease the questionnaire's reliability. Because of modifications to Cunningham and Wescott's instrument for this study, the original validity and reliability of the instrument may have been distorted. An investigation into the internal reliability of the present survey instrument using Cronbach's alpha is currently in progress in order to determine validity and reliability of this modified instrument. Results will be reported as soon as they become available.

In order to improve the instruments' reliability, the questionnaires were presented to two college English faculty members who were asked to critique the items in terms of grammatical correctness, legibility, and comprehension. In addition, the Biological Evolution Concepts section contained in both the teacher's and student's questionnaires was presented to five university science instructors and asked for their assessment of the instrument's items as they pertain to biological evolution and science content. The survey instrument was also presented to 135 university students in seven sections of non-major science courses who were asked to complete the questionnaire and comment on any difficulties they encountered in understanding the meaning of each of the 25 items. Comments and suggested improvements from all parties were considered in revising the questionnaire with regard to clarity, relevance, and accuracy. After revision, it was the consensus of the English and science faculty members that no further revisions were necessary before administering the questionnaire to research subjects.

Data Collection Procedures

This research design will use several specific procedures to ensure that the results obtained are valid and meaningful. A list of all study area high schools will be prepared from information obtained from the 2009-2010 state's Directory of Education (OSDE, 2010). A database will then be created, containing each high school's mailing address. This database will be used as a source for address labels when mailing the study's survey packet and communications to teacher subjects. The science department chair of each high school within the study area will serve as the initial contact person for the study.

Prior to May 1, 2010, a survey packet will be mailed, via first-class U.S. mail, to the science department chair of each high school in the study area. The survey packet will consist of a cover letter which describes the study (see Appendix H), *Informed Consent to Participate in a Research Study* form (see Appendix A), Teacher Questionnaire (see Appendix B), and return mailing materials. The cover letter accompanying the survey packet will request the chair to forward the survey packet to a teacher within the school who will be responsible for teaching a Biology I course section during the 2010-2011 academic year. The cover letter will inform the prospective TS that, should the teacher choose to participate in the study, the subject is to complete the *Informed Consent to Participate in a Research Study* form as well as the TQ. Once these documents are completed, the teacher is instructed to return them to the researcher via the enclosed self-addressed, postage-paid return envelope included in the survey packet. A numerical code printed on the back of each TQ will be used to track nonrespondent high schools and will allow consolidation of survey data. A return date of 14 days following the actual mailing date of the survey packet will be requested on the cover letter as well as the TQ. After a 14-day waiting period, nonrespondent high schools will be identified and the science department chairs of these schools will be contacted via first class mail (see Appendix I). This correspondence will request the chair to encourage the teacher to whom the survey packed was forwarded to return the completed required documents within a ten-day period or to pass the survey packet along to another teacher within the high school who will be teaching a Biology I course section during the 2010-2011 academic year.

Once respondent TS information is acquired, a data-base will be created containing each teacher subject's name, address, telephone number, e-mail address, and estimated number of students in the fall, 2010, Biology I course study section. This information will be used solely for communication purposes for the duration of the study. Following the completion of study data collection, all TS contact information will be destroyed. An e-mail correspondence (see Appendix J) will be sent to all TS in order to verify contact information and to thank TS for their participation in the study.

In addition, the e-mail correspondence will review the TS role in the study for the upcoming 2010-2011 academic year and ask for verification of the number of sets of student questionnaires the TS will require for administration.

Prior to the beginning of fall-term classes at the school study sites, student survey packets will be mailed to each TS via first class mail. Each student survey packet will consist of a cover letter (see Appendix K), *Student Questionnaire Administration Instructions* (see Appendix N), the requested numbers of both the PSQ (see Appendix C) and POSQ (see Appendix D), and postage-paid return mailing materials.

Once TS administer the PSQ (see Appendix C) to SS in a single Biology I course section, TS will be directed via the survey packet cover letter (see Appendix K) to promptly mail the completed questionnaires to the researcher, using the supplied mailing materials. By acquiring the PSQ early in the study, the researcher may begin analysis of data acquired from both the Biological Evolution Concepts and Student Information sections of the questionnaire. An e-mail correspondence prompting participating TS to mail the initial student questionnaire to the researcher (see Appendix M) will be directed to those TS who fail to return the PSQ within a two-week time frame following the beginning of the associated high schools' fall terms. High school starting dates will be identified via school websites and telephone communication.

An additional e-mail correspondence (see Appendix N) will be sent to those TS who return the completed PSQ (see Appendix C). This communication will thank the TS for their participation and remind them of the criteria for administering the POSQ (see Appendix D) later in the course. Additional e-mail communications will be sent at regular intervals to those TS who through the course of the academic year have yet to administer and return the POSQ (see Appendix D) in order to remind them of their impending task.

Data Analysis

Because recent literature indicates that results of survey work with students about their knowledge and attitudes concerning evolutionary biology and the nature of sciences appear to be lacking in terms of the robustness of statistical methods (Goldstein, 2010), great care will be undertaken in this study to ensure that appropriate statistical methods are employed and that the resulting data is robust and correctly interpreted.

Once it becomes apparent that all available survey data have been acquired, data analysis will proceed. Data from both teacher and student subject questionnaires will be entered into an Microsoft® Excel® (Excel) spreadsheet along with institutional ADM data acquired from the OSSAA (2010) and institutional affiliation data acquired from the 2009-2010 state's Directory of Education (OSDE, 2010). Descriptive statistics will be obtained by using Excel formulas while inferential statistical analysis of the data will be performed with IBM® SPSS® (SPSS) statistical software. Data analysis will be conducted for each of the following data categories:

1. Institution data
2. Teacher subject information data
3. Student subject information data
4. Biological evolution misconceptions held by secondary school life science teachers

5. Biological evolution misconceptions held by secondary school life science students prior to instruction in biological evolution curriculum
6. Biological evolution misconceptions held by secondary school life science students following instruction in biological evolution curriculum
7. Relationship of student-held biological evolution misconceptions prior to and following instruction in biological evolution curriculum
8. Relationship of teacher-held biological evolution misconceptions with student-held biological evolution misconceptions prior to student instruction in biological evolution curriculum
9. Relationship of teacher-held biological evolution misconceptions with student-held biological evolution misconceptions following student instruction in biological evolution curriculum

A chi-square (X^2) goodness-of-fit test is used to determine how closely observed frequencies or probabilities match expected frequencies or probabilities (Leedy & Ormrod, 2001). Institutional characteristics such as ADM and affiliation will be analyzed by chi-square tests of independent samples in order to determine if the participating institutions in the sample are representative of the institution population within the sampling area. In addition, teacher and SS information data will be analyzed by chi-square tests of independent samples in order to determine whether the sample subjects are representative of their respective populations. Characteristics such as the number of biological evolution misconceptions held and the number of misconceptions in each biological evolution misconception category will be analyzed by descriptive statistical methods including frequency counts, percentages, and means for both the teacher and student subjects.

The number and categories of biological evolution misconceptions held by SS prior to and following instruction in biological evolution curriculum will be analyzed by the *t*-test and one-way analysis of variance (ANOVA), two tests commonly used to compare two or more groups or study changes that take place in the same group from one time to the next (Fink & Kosecoff, 1998; Lomax, 2007). The *t*-test is used to determine whether a statistically significant difference exists between two means whereas ANOVA is used to examine the differences among three or more means by comparing the variances (s^2) both within and across groups (Leedy & Ormrod, 2001).

Correlation of teacher-held biological evolution misconceptions with student-held biological evolution misconceptions both prior to and following student instruction in biological evolution curriculum will be analyzed using Pearson product-moment correlation coefficient (Pearson's *r*) as well as ANOVA. Pearson's *r* is used to measure the relationship among two variables in terms of the magnitude (weak to strong) and direction of the relationship (positive or negative/inverse; Nardi, 2006). ANOVA analysis indicating significant differences ($p < .05$) will be further examined by a series of ad hoc multiple comparison tests including Tukey HSD, Tukey-Kramer, Fisher LSD, and Hayter tests (Lomax, 2007).

Summary of the Methodology

The purpose of this chapter is to describe the methodology used to collect information concerning the role of secondary school life science teachers in student acquisition of biological evolution-related misconceptions. A total of 484 high schools in a Southern state will be selected as sample sites for the study. Within each sample site, a single secondary school Biology I teacher will be recruited for participation along with a single section of the teacher's Biology I course students.

BEL survey packets which include a cover letter (see Appendix H), Informed Consent to Participate in a Research Study form (see Appendix A), TQ (see Appendix B), and return mailing materials, will be mailed to the science department chair of each of the study sites identified 484 high schools prior to May 1, 2010. The chair will be requested to pass the BEL survey packet on to a secondary school teacher who will be teaching at least one section of Biology I during the 2010-2011 academic year. The questionnaire instrument will collect information concerning teacher characteristics such as education and work experience and, using a Likert scale, categories and levels of biological evolution misconceptions held will be identified. TS will be enrolled into the study upon receipt of the *Informed Consent to Participate in a Research Study* form and TQ by the researcher. Subsequently, TS will be sent both PSQ and POSQ (see Appendixes C and D) to be administered to one section of Biology I students prior to and following biological evolution curriculum instruction during the course of the 2010-2011 academic year.

Once the survey data have been acquired by the researcher, data analysis will commence. Descriptive and inferential statistical methods of analysis including frequency and percentage counts, mean, chi-square test, and ANOVA will initially provide data describing the characteristics of the sample site institutions, teacher and student subjects, and the number and classes of biological evolution misconceptions held by both groups of subjects. The *t*-test and ANOVA inferential statistical methods of analysis will then be employed to acquire data describing the relationships between student pre- and post-instruction biological evolution misconception number and classes. In addition, ANOVA and Pearson's *r* inferential analysis methods will illuminate the relationship between pre- and post-instruction student biological evolution misconception numbers and classes and those of their respective life science teachers.

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APPENDIX

Appendix A: Informed Consent to Participate in a Research Study Form

University of Oklahoma
Institutional Review Board
Informed Consent to Participate in a Research Study

Project Title: A Regional Study of Biological Evolution Literacy in Secondary Schools (IRB # 12982)

Principal Investigator: Tony Yates

Department: Instructional Leadership and Academic Curriculum

You are being asked to volunteer for this research study. This study is being conducted at the high school where you are employed. You were selected as a possible participant because you are a current life science teacher employed by an Oklahoma high school who will be teaching at least one section of Biology I during the 2010-2011 academic year. You were selected as a possible participant for this study by direct contact with your school's science chair. Please read this form and ask any questions that you may have before agreeing to take part in this study.

Purpose of the Research Study

The purpose of this study is to identify the level of biological evolution literacy in Oklahoma secondary school life science classrooms.

Number of Participants

Approximately 50-350 people will take part in this study.

Procedures

If you agree to be in this study, you will be asked to complete a survey and provide contact information for follow up activities.

Length of Participation

Time required to complete the contact information and survey will be approximately 30 minutes.

This study has the following risks:

There are no risks associated with this study. Participants may withdraw from the study at any time. Some research designs require that the full intent of the study not be explained prior to participation.

Benefits of being in the study are:

None

Confidentiality

In published reports, there will be no information included that will make it possible to identify you without your permission. Research records will be stored securely and only approved researchers will have access to the records.

There are organizations that may inspect and/or copy your research records for quality assurance and data analysis. These organizations include the OU Institutional Review Board.

Compensation

You will not be reimbursed for your time and participation in this study.

Voluntary Nature of the Study

Participation in this study is voluntary. If you withdraw or decline participation, you will not be penalized or lose benefits or services unrelated to the study. If you decide to participate, you may decline to answer any question and may choose to withdraw at any time.

Contacts and Questions

If you have concerns or complaints about the research, the researcher conducting this study can be contacted via telephone at (405) 878.2098 or (405) 220.4139, or via e-mail at tony.yates@okbu.edu. The researcher's advisor can be contacted via phone at (405) 325-1498 or 325-5723, or via e-mail at eamarek@ou.edu.

Contact the researcher(s) if you have questions or if you have experienced a research-related injury.

If you have any questions about your rights as a research participant, concerns, or complaints about the research and wish to talk to someone other than individuals on the research team or if you cannot reach the research team, you may contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu.

You will be given a copy of this information to keep for your records. If you are not given a copy of this consent form, please request one.

Statement of Consent

I have read the above information. I have asked questions and have received satisfactory answers. I consent to participate in the study.

____

Signature **Date**

The following information is required for communication purposes only.

Teacher's name:____

School:____

E-mail address:____

School contact phone number:____

Estimated number of students in the fall, 2010, Biology I study section:___________

*Please mail this completed Informed Consent to Participate in a Research Study form along with the completed Teacher Questionnaire in the enclosed self-address, postage-paid envelope by **May 10, 2010.***

Thank you.

Biological Evolution Literacy

A Regional Study of Biological Evolution Literacy in Secondary Schools

Thank you for participating in this study concerning biological evolution education. The data you provide will be valuable to those concerned with improving scientific literacy.

I. Biological Evolution Concepts

In this section your opinions concerning biological evolution concepts will be identified. Use the following scale to indicate how strongly you agree or disagree with each statement by circling the number that best represents your opinion.

1- strongly agree
2- somewhat agree
3- somewhat disagree
4- strongly disagree
5- undecided/never heard of it

1. A scientific theory that explains a natural phenomenon can be defined as a "best guess" or "hunch". …………………………………………………………………1 2 3 4 5

2. The scientific methods used to determine the age of fossils and the earth are reliable………………………………………………………………………………1 2 3 4 5

3. According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms…………………………………………………………...1 2 3 4 5

4. The earth is old enough for evolution to have occurred……………………………..…1 2 3 4 5

5. Evolution cannot be considered a reliable explanation because evolution is only a theory……………………………………………………………………….…..1 2 3 4 5

6. Evolution always results in improvement. …………………………………………..…1 2 3 4 5

7. Members of a species evolve because of an inner need to change…………………..…1 2 3 4 5

8. Traits acquired during the lifetime of an organism (for example, large muscles produced by body building) will not be passed along to offspring………………………1 2 3 4 5

9. If evolution selects for webbed feet, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation……....1 2 3 4 5

10. Evolution cannot cause an organism's traits to change within its lifetime……………..1 2 3 4 5

11. New traits within a population appear at random……………………………………1 2 3 4 5

12. The environment determines which traits appear in a population……………………...1 2 3 4 5

13. By means of evolution, individual organisms adapt to their environments……………1 2 3 4 5

14. Evolution is a totally random process………………………………………………..1 2 3 4 5

15. The environment determines which traits are best suited for survival…………………1 2 3 4 5

16. Variation among individuals within a species is important for evolution to occur……1 2 3 4 5

(continued on following page)

17. "Survival of the fittest" means basically that "only the strong survive"………………..1 2 3 4 5

18. The size of the population has no effect on the evolution of a species………………...1 2 3 4 5

19. Complex structures such as the eye could have been formed by evolution…………....1 2 3 4 5

20. Only beneficial traits are passed on from parent to offspring…………………………..1 2 3 4 5

21. There exists a large amount of evidence supporting the theory of evolution…………..1 2 3 4 5

22. According to the theory of evolution, humans evolved from monkeys, gorillas, or apes…………………………………………………………………………...1 2 3 4 5

23. Scientific evidence indicates that dinosaurs and humans lived at the same time in the past……………………………………………………………………………..1 2 3 4 5

24. The majority of scientists favor evolution over other explanations for life's diversity...1 2 3 4 5

25. Transitional fossils which represent intermediate forms between species are rare…..…1 2 3 4 5

II. Instructor and Course Information

Please complete this section of the questionnaire concerning instructor and course information.

1. Gender:

   a) ____ male b) ____ female

2. What is your highest earned degree?

   a) ____ bachelor

   b) ____ master

   c) ____ doctorate

   d) ____ other

3. Identify your degree major.

   bachelor degree________________________

   master degree ________________________

   doctoral degree ________________________

4. Rate the emphasis given to evolution education in your college courses.

   a) ____ not emphasized

   b) ____ slightly emphasized

   c) ____ moderately emphasized

   d) ____ highly emphasized

5. Identify your years of teaching experience.

   a) ____ 0-5

   b) ____ 6-10

   c) ____ 11-15

   d) ____ 16-20

   e) ____ more than 20

6. Are you a certified biology teacher?

   a) ____ yes b) ____ no

7. What is your current employment status?

   a) ____ full time b) ____ part time

8. Identify your current primary teaching duty.

   ____

9. How many sections of the Biology I course have you taught? ________

10. How many hours do you dedicate to the teaching of evolution concepts in a single Biology I course section?

    a) ____ 0

    b) ____ 1-5

    c) ____ 6-10

    d) ____ 11-15

    e) ____ 16+

11. Rate your knowledge of evolution.

    a) ____ excellent

    b) ____ good

    c) ____ average

    d) ____ fair

    e) ____ poor (continued on following page)

12. Please respond by circling the number that best represents the emphasis you place on each of the following concepts when teaching the Biology I course.

	None	Mild	Moderate	Strong
a. Species evolve over time due to evolutionary processes.	1	2	3	4
b. Species diversity is produced by evolution.	1	2	3	4
c. Darwin's theory of natural selection.	1	2	3	4
d. Relatedness of species due to common descent.	1	2	3	4
e. Environmental resources effect on population size.	1	2	3	4
f. Competition among organisms inhabiting the same environment.	1	2	3	4
g. Genetic variability among offspring due to mutation and recombination of genes.	1	2	3	4
h. Biological classification based on evolutionary relationships.	1	2	3	4

13. How many sections of Biology I were taught at your school during the 2009-2010 academic year?

____

14. How many different teachers taught at least one section of the Biology I course during the 2009-2010 academic year? __________

15. Identify the time frame for teaching Biology I at your school for the 2010-2011 academic year. Check all that apply.

a) ____ One semester course offered fall semester only

b) ____ One semester course offered spring semester only

c) ____ One semester course offered both fall and spring semesters

d) ____ Two semester course

Please mail this completed Teacher Questionnaire along with the completed Informed Consent to Participate in a Research Study form in the enclosed self-addressed, postage-paid envelope by ***May 10, 2010.***

Thank you.

Appendix C: Pre-instruction Student Questionnaire

Thank you for participating in this study concerning biological evolution education. The data you provide will be valuable to those concerned with improving scientific literacy. Please answer each question to the best of your ability. Your name is not required and all information you provide will remain anonymous.

I. Biological Evolution Concepts

In this section your opinions concerning biological evolution concepts will be identified. Use the following scale to indicate how strongly you agree or disagree with each statement by circling the number that best represents your opinion.

1- strongly agree
2- somewhat agree
3- somewhat disagree
4- strongly disagree
5- undecided/never heard of it

1. A scientific theory that explains a natural phenomenon can be defined as a "best guess" or "hunch". ……………………………………………………………….1 2 3 4 5

2. The scientific methods used to determine the age of fossils and the earth are reliable……………………………………………………………………………1 2 3 4 5

3. According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms………………………………………………………...1 2 3 4 5

4. The earth is old enough for evolution to have occurred…………………………..…1 2 3 4 5

5. Evolution cannot be considered a reliable explanation because evolution is only a theory…………………………………………………………………….…..1 2 3 4 5

6. Evolution always results in improvement. …………………………………….…1 2 3 4 5

7. Members of a species evolve because of an inner need to change……………….…1 2 3 4 5

8. Traits acquired during the lifetime of an organism (for example, large muscles produced by body building) will not be passed along to offspring………………………1 2 3 4 5

9. If evolution selects for webbed feet, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation……....1 2 3 4 5

10. Evolution cannot cause an organism's traits to change within its lifetime……………..1 2 3 4 5

11. New traits within a population appear at random………………………………………1 2 3 4 5

12. The environment determines which traits appear in a population……………………...1 2 3 4 5

13. By means of evolution, individual organisms adapt to their environments……………1 2 3 4 5

14. Evolution is a totally random process…………………………………………………..1 2 3 4 5

15. The environment determines which traits are best suited for survival…………………1 2 3 4 5

16. Variation among individuals within a species is important for evolution to occur….…1 2 3 4 5

(continued on following page

Scale:

1- strongly agree
2- somewhat agree
3- somewhat disagree
4- strongly disagree
5- undecided/never heard of it

17. "Survival of the fittest" means basically that "only the strong survive"………………..1 2 3 4 5

18. The size of the population has no effect on the evolution of a species………………....1 2 3 4 5

19. Complex structures such as the eye could have been formed by evolution…………......1 2 3 4 5

20. Only beneficial traits are passed on from parent to offspring…………………………..1 2 3 4 5

21. There exists a large amount of evidence supporting the theory of evolution…….……..1 2 3 4 5

22. According to the theory of evolution, humans evolved from monkeys, gorillas, or apes………………………………………………………………………………...1 2 3 4 5

23. Scientific evidence indicates that dinosaurs and humans lived at the same time in the past……………………………………………………………………………..1 2 3 4 5

24. The majority of scientists favor evolution over other explanations for life's diversity...1 2 3 4 5

25. Transitional fossils which represent intermediate forms between species are rare…..…1 2 3 4 5

II. Student Information

Please complete this section of the questionnaire concerning student and course information. Your name is not required and all information you provide will remain anonymous.

1. Which is your gender?

   a) ____ male b) ____ female

2. Which is your ethnicity?

   a) ____American Indian or Alaska Native
   b) ____Asian or Pacific Islander
   c) ____Black, non-Hispanic
   d) ____Hispanic
   e) ____White, non-Hispanic

3. Which is your current class?

   a) ____freshman
   b) ____sophomore
   c) ____junior
   d) ____senior
   e) ____other

4. Have you taken a Biology I course prior to this one?

   a) ____ yes b) ____ no

5. Rate your current knowledge of evolution.

   a) ____ excellent
   b) ____ good
   c) ____ average
   d) ____ fair
   e) ____ poor

6. Identify the following:

   a) What shoe size do you wear? __________
   b) What is your birth month?____________
   c) How many brothers do you have? ______
   d) How many sisters do you have? _______

Thank you!

Appendix D: Post-instruction Student Questionnaire

Thank you for participating in this study concerning biological evolution education. The data you provide will be valuable to those concerned with improving scientific literacy. Please answer each question to the best of your ability. Your name is not required and all information you provide will remain anonymous.

I. Biological Evolution Concepts

In this section your opinions concerning biological evolution concepts will be identified. Use the following scale to indicate how strongly you agree or disagree with each statement by circling the number that best represents your opinion.

1- strongly agree
2- somewhat agree
3- somewhat disagree
4- strongly disagree
5-undecided/never heard of it

1. A scientific theory that explains a natural phenomenon can be defined as a "best guess" or "hunch". ……………………………………………………………….1 2 3 4 5

2. The scientific methods used to determine the age of fossils and the earth are reliable…………………………………………………………………………………1 2 3 4 5

3. According to the second law of thermodynamics, complex life forms cannot evolve from simpler life forms………………………………………………………...1 2 3 4 5

4. The earth is old enough for evolution to have occurred…………………………….…1 2 3 4 5

5. Evolution cannot be considered a reliable explanation because evolution is only a theory………………………………………………………………………….…..1 2 3 4 5

6. Evolution always results in improvement. ………………………………………….…1 2 3 4 5

7. Members of a species evolve because of an inner need to change……………………..…1 2 3 4 5

8. Traits acquired during the lifetime of an organism (for example, large muscles produced by body building) will not be passed along to offspring………………………1 2 3 4 5

9. If evolution selects for webbed feet, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation……....1 2 3 4 5

10. Evolution cannot cause an organism's traits to change within its lifetime……………..1 2 3 4 5

11. New traits within a population appear at random………………………………………1 2 3 4 5

12. The environment determines which traits appear in a population……………………...1 2 3 4 5

13. By means of evolution, individual organisms adapt to their environments……………1 2 3 4 5

14. Evolution is a totally random process………………………………………………..1 2 3 4 5

15. The environment determines which traits are best suited for survival…………………1 2 3 4 5

16. Variation among individuals within a species is important for evolution to occur……1 2 3 4 5

(continued on following page)

Scale:

1- strongly agree
2- somewhat agree
3- somewhat disagree
4- strongly disagree
5- undecided/never heard of it

17. "Survival of the fittest" means basically that "only the strong survive"………………..1 2 3 4 5

18. The size of the population has no effect on the evolution of a species………………....1 2 3 4 5

19. Complex structures such as the eye could have been formed by evolution…………....1 2 3 4 5

20. Only beneficial traits are passed on from parent to offspring…………………………..1 2 3 4 5

21. There exists a large amount of evidence supporting the theory of evolution……..……..1 2 3 4 5

22. According to the theory of evolution, humans evolved from monkeys, gorillas, or apes………………………………………………………………………………...1 2 3 4 5

23. Scientific evidence indicates that dinosaurs and humans lived at the same time in the past……………………………………………………………………………..1 2 3 4 5

24. The majority of scientists favor evolution over other explanations for life's diversity...1 2 3 4 5

25. Transitional fossils which represent intermediate forms between species are rare…..…1 2 3 4 5

II. Student Information

Please complete this section of the questionnaire concerning student and course information. Your name is not required and all information you provide will remain anonymous.

1. Which is your gender?
   a) ____ male b) ____ female

2. Which is your ethnicity?
   a) ____American Indian or Alaska Native
   b) ____Asian or Pacific Islander
   c) ____Black, non-Hispanic
   d) ____Hispanic
   e) ____White, non-Hispanic

3. Which is your current class?
   a) ____freshman
   b) ____sophomore
   c) ____junior
   d) ____senior
   e) ____other

4. Have you taken a Biology I course prior to this one?
   a) ____ yes b) ____ no

5. Rate your current knowledge of evolution.
   a) ____ excellent
   b) ____ good
   c) ____ average
   d) ____ fair
   e) ____ poor

6. Identify the following:
   a) What shoe size do you wear? __________
   b) What is your birth month? ____________
   c) How many brothers do you have? ______
   d) How many sisters do you have? _______

Thank you!

Appendix E: Biological Evolution National Science Education Standards for Grades 9-12

Biological evolution is one of six primary areas of the National Science Education Standards [NSES] *Life Science's Content Standard C* where all grade 9-12 students should develop understanding (NRC, 1996). Five fundamental concepts underlie the *NSES* biological evolution component of *Life Science Content Standard C.* First, species evolve over time due to evolutionary processes (NRC, 1996). Forces that drive biological evolution are explained:

> Evolution is the consequence of the interactions of the potential for a species to increase its numbers; the genetic variability of offspring due to mutation and recombination of genes; a finite supply of the resources required for life, and; the ensuing selection by the environment of those offspring better able to survive and leave offspring. (NRC, 1996, p. 185)

Second, Earth's great diversity of life is addressed in *Life Science Content Standard C*: "The great diversity of organisms on our planet is the result of more than 3.5 billion years of evolution that has filled every available niche with life forms" (NRC, 1996, p. 185). Third, the implications of Darwin's theory of natural selection are presented: "Natural selection and its evolutionary consequences provide a scientific explanation for the fossil record of ancient life forms, as well as for the striking molecular similarities observed among the diverse species of living organisms" (NRC, 1996, p. 185). Next, relatedness via descent from common ancestors is illuminated: "The millions of different species of plants, animals, and microorganisms that live on earth today are related by descent from common ancestors" (NRC, 1996, p. 185).

Finally, the relationship of biological classification to evolution is explained: “Biological classifications are based on how organisms are related. Organisms are classified into a hierarchy of groups and subgroups based on similarities which reflect their evolutionary relationships with the species being the most fundamental unit of classification” (NRC, 1996, p. 185).

Appendix F: Biological Evolution Priority Academic Student Skills for Grades 9-12

Priority Academic Student Skills [PASS] standards and objectives for specific subject areas are presented independent of grade level for grades 9-12 (OSDE, 2009b). The Biology I curriculum possesses several content standards that emphasize biological evolution-related concepts.

Standard 3: Biological Diversity

> Diversity of species is developed through gradual processes over many generations. (OSDE, 2009b, p. 210):
>
> *Objective 3.1: Different species might look dissimilar, but the unity among organisms becomes apparent from an analysis of internal structures, the similarity of their chemical processes, and the evidence of common ancestry (e.g., homologous and analogous structures)* (OSDE, 2009b, p. 210).
>
> *Objective 3.2: Species acquire many of their unique characteristics through biological adaptation, which involves the selection of naturally occurring variations in populations. Biological adaptations include changes in structures, behaviors, or physiology, which may enhance or limit the survival and reproduction success in a particular environment* (OSDE, 2009b, p. 210).

Standard 3 emphasizes multiplication of species via gradual evolving change. *Objective 3.1* stresses common descent as the explanation for similarities among organisms, whereas *Objective 3.2* underscores natural selection as the means for species acquiring their unique characteristics.

Standard 4: The Interdependence of Organisms

> Interrelationships and interactions between and among organisms in an

environment is the interdependence of organisms (OSDE, 2009b, p. 211).

Objective 4.2. Organisms both cooperate and compete in ecosystems (i.e., parasitism and symbiosis; OSDE, 2009b, p. 211).

Objective 4.2 emphasizes competition among organisms inhabiting the same environment. Such competition is an integral principle of natural selection which, in turn, can lead to new adaptations within the population and the origination of new species.

Objective 4.3: Living organisms have the capacity to produce populations of infinite size, but environments and resources limit population size (OSDE, 2009b, p. 211).

In *Objective 4.3* competition is once again emphasized. This form of competition, however, is between organisms and their environments rather than competition between organisms themselves. This objective highlights the concept of fitness in which those members of the population that are better designed for the immediate local environment possess a better probability of survival than those members of the populations that lack such adaptations. As stated by Smith and Sullivan (2007), fitness is ". . . a measure of an individual's reproductive potential" (p. 16). Fitness, like competition, is yet another foundational principle of the theory of natural selection.

Appendix G: Cunningham and Westcott Permission Correspondence

3.15.10

Hi Tony,

Thanks for contacting us. It sounds like you have an interesting dissertation topic. Yes, of course you may modify our instrument to use in your dissertation. Just be aware that many of our questions/statements are from others. Almquist & Cronin is one source, but there were several others as well (Wilson, Bishop & Anderson). You may want to go to these original sources as well. Please let us know if you need any assistance in your journey through dissertation-land! We were both there ourselves not too long ago. And do let us know your results.

Best of luck,

Deborah

Deborah L. Cunningham, Ph.D.
Clinical Assistant Professor
Florida Atlantic University

Appendix H: Teacher Survey Packet Cover Letter

the university of OKLAHOMA

SCIENCE EDUCATION CENTER

<Date>, 2010

<<Department Chair>>

Please forward this letter and questionnaire to a life science instructor responsible for teaching a Biology I course section during the fall 2010 semester.

Dear Biology I Instructor,

As an educator, you are no doubt concerned with the current level of scientific literacy exhibited by the general public, your students, and fellow educators. Improving society's scientific literacy may be addressed in several ways once the levels of scientific literacy among various groups are established and influencing factors are identified. I am requesting your participation in a study to identify the current state of biological evolution literacy in Oklahoma secondary schools as well as those factors that influence such literacy rates.

Your participation will initially involve completing and returning the enclosed *Informed Consent to Participate in a Research Study* form and *Teacher Questionnaire.* Subsequently, you will be asked to administer a similar questionnaire to a single section of your Biology I course students at the beginning of the fall, 2010, semester and once again following completion of biological evolution curriculum instruction or simply upon the completion of the course in the spring of 2011. This study will provide important information to those interested in improving scientific literacy in Oklahoma's secondary schools.

I appreciate your assistance in this study, and ask that you return the enclosed items by **May 10**, 2010. By doing so, you indicate your willingness to participate in the study. All information collected will be held strictly confidential, and no specific teacher, student, or institution will be associated in any way with the collected data. I have requested your name and e-mail address on the enclosed form for coordination and questionnaire distribution purposes only. Thank you very much for your time, cooperation, and willingness to improve scientific literacy in Oklahoma. If you are not interested in participating in this study, please pass this survey packet along to a colleague in your school who will be teaching a Biology I course section next fall.

Sincerely,

Tony B. Yates
Assistant Professor of Natural Sciences
Oklahoma Baptist University
(Doctoral candidate, University of Oklahoma)
405.878.2098   tony.yates@okbu.edu

Enclosure (2)

The University of Oklahoma is an Equal Opportunity Institution.

Appendix I: Nonrespondent Contact Correspondence

the university of OKLAHOMA
SCIENCE EDUCATION CENTER

<Date>

Science Department Chair,

This is a follow-up to our previous correspondence requesting your participation in a study to determine the current state of biological evolution literacy in Oklahoma's secondary schools and those factors that influence such literacy rates.

Your input is very important. Please encourage the instructor to whom you forwarded the *Biological Evolution Literacy* survey packet to return the *Informed Consent to Participate in a Research Study* form and *Teacher Questionnaire* by **May 30**. If you need another copy of the survey packet please contact me via e-mail at: tony.yates@okbu.edu. Thank you very much for your cooperation in this endeavor.

Sincerely,

Tony B. Yates
Assistant Professor of Natural Science
Oklahoma Baptist University
405.878.2098
tony.yates@okbu.edu

The University of Oklahoma is an Equal Opportunity Institution.

Appendix J: Student Questionnaire Number Verification E-mail

<Date>

Dear <Name>,

Thank you for participating in this study which is attempting to identify the current levels of biological evolution literacy in Oklahoma secondary schools and those factors that influence such literacy rates. Your participation in this study is greatly appreciated.

Student data collection requires that you administer a *Pre-instruction Student Questionnaire* to students in one Biology I course section during the first week of the fall term, if possible. The *Pre-instruction Student Questionnaire* is to be followed by administration of the *Post-instruction Student Questionnaire* once instruction in biological evolution curriculum is completed or simply near the completion of the Biology I course.

You have indicated to me that you will require <number> sets of the student questionnaires. If this number is inaccurate, please relay to me via e-mail the correct number of sets of student questionnaires you will require. I will mail both sets of questionnaires, instructions for administering the questionnaires, and postage-paid return mailing materials to you prior to the start of classes at your school.

Again, thank you for your efforts in this endeavor. If you have any questions concerning the study, please contact me.

Sincerely,

Tony B. Yates
Assistant Professor of Natural Science
Oklahoma Baptist University
405.878.2098
Tony.yates@okbu.edu

Appendix K: Student Survey Packet Cover Letter

the university of OKLAHOMA

SCIENCE EDUCATION CENTER

<Date>

Dear <Name>,

Thank you for participating in this study which is attempting to identify the current levels of biological evolution literacy in Oklahoma secondary schools and those factors that influence such literacy rates. Your participation in this study is greatly appreciated.

Student data collection requires that you administer the *Pre-instruction Student Questionnaire* to students in one Biology I course section during the first week of the fall term. If you are unable to administer the questionnaire during the first week of the term, please administer the questionnaire as soon as possible. Once you have administered the *Pre-instruction Student Questionnaire* to your students please return the questionnaire in the enclosed self-addressed, postage-paid envelope.

Administration of the *Pre-instruction Student Questionnaire* is to be followed by administration of the *Post-instruction Student Questionnaire* once course instruction in biological evolution curriculum is completed or simply near the completion of the Biology I course. Once administration has occurred, please return the *Post-instruction Student Questionnaire* in the second enclosed self-addressed, postage-paid envelope.

A *Questionnaire Administration Instructions* document is included in this mailing. Please read this document prior to administering each of the two student questionnaires.

Again, thank you for your efforts in this endeavor. If you have any questions concerning the study, please contact me.

Sincerely,

Tony B. Yates
Assistant Professor of Natural Science
Oklahoma Baptist University
405.878.2098   tony.yates@okbu.edu

Enclosures (3)

The University of Oklahoma is an Equal Opportunity Institution.

Appendix L: Student Questionnaire Administration Instructions

Administration of the *Pre-instruction Student Questionnaire*

The *Pre-instruction Student Questionnaire* is to be administered during the first week of the fall, 2010, semester or as soon as possible thereafter.

1. Give each student a copy of the *Pre-instruction Student Questionnaire*.

2. Read the following to your students:

   You are about to complete a questionnaire concerning biological evolution concepts. This questionnaire is part of a research project and your participation will remain anonymous. In Part I you will read each statement and then circle the number that best represents your opinion of the statement. If you strongly agree with the statement, you will circle number one; if you somewhat agree with the statement, you will circle number two; if you somewhat disagree with the statement, you will circle number three; if you strongly disagree with the statement, you will circle number four; and, if you are undecided or have never heard of the statement, you will circle number 5. In Part II you will supply information about yourself. Please read each statement thoroughly and answer to the best of your ability.

3. Once the *Pre-instruction Student Questionnaire has* been collected, please mail as soon as possible in the enclosed self-addressed, postage-paid envelope.

Administration of the *Post-instruction Student Questionnaire*

1. Give each student a copy of the *Post-instruction Student Questionnaire*.

2. Read to your students the identical instructions found in statement number two above.

3. Once the *Post-instruction Student Questionnaire has* been collected, please mail as soon as possible in the enclosed self-addressed, postage-paid envelope.

Appendix M: Student Pre-instruction Questionnaire Mailing Request E-mail

<Date>

Dear <Name>,

Thank you for participating in this study which is attempting to identify the current levels of biological evolution literacy in Oklahoma secondary schools and those factors that influence such literacy rates. Your participation in this study is greatly appreciated.

At this time you should have administered the *Pre-instruction Student Questionnaire* to students in one Biology I course section. If you have done so, please mail the completed questionnaires to me in the self-address, postage-paid envelope that was supplied with your survey packet. If you have not yet administered the *Pre-instruction Student Questionnaire* to students in one Biology I course section, please do so as soon as possible and mail the surveys.

Again, thank you for your support in this research endeavor.

Sincerely,

Tony Yates
Assistant Professor of Natural Sciences
Oklahoma Baptist University
405.878.2098
tony.yates@okbu.edu

Appendix N: Teacher Subject Student Post-instruction Questionnaire Criteria E-mail

<Date>

Dear <Name>,

Thank you for returning to me the *Pre-instruction Student Questionnaires*. I have received them and have begun the data analysis process. Thank you as well for participating in this study which is attempting to identify the current levels of biological evolution literacy in Oklahoma secondary schools and those factors that influence such literacy rates. Your participation in this study is greatly appreciated and needed.

Administration of the *Pre-instruction Student Questionnaire* is to be followed by administration of the *Post-instruction Student Questionnaire* once course instruction in biological evolution curriculum is completed or simply near the completion of the Biology I course. Once administration of the survey has occurred, please return the *Post-instruction Student Questionnaires* in the self-addressed, postage-paid envelope which you received with the questionnaire mailing.

Again, thank you for your efforts in this endeavor. If you have any questions concerning the study, please contact me.

Sincerely,

Tony B. Yates
Assistant Professor of Natural Science
Oklahoma Baptist University
405.878.2098
tony.yates@okbu.edu

APPENDIX B: INTERNAL REVIEW BOARD

The University of Oklahoma

OFFICE FOR HUMAN RESEARCH PARTICIPANT PROTECTION

IRB Number: 12982
Approval Date: April 19, 2010

April 19, 2010

Tony Yates
Instructional Leadership and Academic Curriculum
712 Hidden Lake Drive
Seminole, OK 74868

RE: The Role of Secondary School Life Science Teachers in Student Acquisition of Biological Evolution-Related Misconceptions.

Dear Mr. Yates:

On behalf of the Institutional Review Board (IRB), I have reviewed and granted expedited approval of the above-referenced research study. This study meets the criteria for expedited approval category 7. It is my judgment as Chairperson of the IRB that the rights and welfare of individuals who may be asked to participate in this study will be respected; that the proposed research, including the process of obtaining informed consent, will be conducted in a manner consistent with the requirements of 45 CFR 46 as amended; and that the research involves no more than minimal risk to participants.

This letter documents approval to conduct the research as described:

Protocol Dated: April 15, 2010 Revised
Other Dated: April 15, 2010 Recruitment Letter - Teacher Survey - Revised
Survey Instrument Dated: April 15, 2010 Post-Instruction Student Questionnaire - Revised
Survey Instrument Dated: April 15, 2010 Pre-Instruction Student Questionnaire - Revised
Survey Instrument Dated: April 15, 2010 Teacher Questionnaire - Revised
Consent form - Subject Dated: April 15, 2010 Revised
IRB Application Dated: April 12, 2010 Revised
Other Dated: April 08, 2010 Recruitment Email - Student Post-Instruction Quest
Other Dated: April 08, 2010 Teacher Contact Information Form
Other Dated: April 08, 2010 Nonrespondant Contact Correspondance
Other Dated: April 08, 2010 Recruitment Email - Student Questionnaire
Other Dated: April 08, 2010 Recruitment Letter - Student Survey
Other Dated: April 08, 2010 Student Questionnaire Administration Instructions
Other Dated: April 08, 2010 Debrief
Other Dated: April 08, 2010 Recruitment Email - Student Pre-Instruction Quest
Other Dated: April 08, 2010 Student Questionnaire Number Form

As principal investigator of this protocol, it is your responsibility to make sure that this study is conducted as approved. Any modifications to the protocol or consent form, initiated by you or by the sponsor, will require prior approval, which you may request by completing a protocol modification form. All study records, including copies of signed consent forms, must be retained for three (3) years after termination of the study.

The approval granted expires on April 18, 2011. Should you wish to maintain this protocol in an active status beyond that date, you will need to provide the IRB with an IRB Application for Continuing Review (Progress Report) summarizing study results to date. The IRB will request an IRB Application for Continuing Review from you approximately two months before the anniversary date of your current approval.

If you have questions about these procedures, or need any additional assistance from the IRB, please call the IRB office at (405) 325-8110 or send an email to irb@ou.edu.

Cordially,

Aimee Franklin, Ph. D
Vice Chair, Institutional Review Board

Oval, Suite 316, Norman, Oklahoma 73019-3085 PHONE: (405) 325-8110 FAX:(405) 325-2373

The University of Oklahoma®

OFFICE OF HUMAN RESEARCH PARTICIPANT PROTECTION - IRB

IRB Number: 12982
Approval Date: February 28, 2011

February 28, 2011

Tony Yates
Oklahoma Bapist University
500 West university / OBU Box 61772
Shawnee, OK 74804

RE: The Role of Secondary School Life Science Teachers in Student Acquisition of Biological Evolution-Related Misconceptions.

Dear Mr. Yates:

Thank you for completing and returning the IRB Application for Continuing Review (Progress Report) for the above-referenced study. You have indicated that the study is still active. I have reviewed and approved the Progress Report and determined that this study was appropriate for continuation.

This letter documents approval to conduct the research as described in:
Cont Review Form Dated: February 15, 2011
Protocol Dated: February 15, 2011
Other Dated: February 15, 2011 Summary of study results
Consent form - Subject Dated: February 15, 2011

Please remember that any change in the protocol, consent document or other recruitment materials (adverstisements, etc.) must be approved by the IRB prior to its incorporation into the study procedures. Submit a completed Protocol Modification form to the IRB office.

Approximately two months prior to the expiration date of this approval, you will be contacted by the IRB staff about procedures necessary to maintain this approval in an active status. Although every attempt will be made to notify you when a study is due for review, it is the responsibility of the investigator to assure that their studies receive review prior to expiration.

The approval of this study expires on February 27, 2012 and must be reviewed by the convened IRB prior to this time if you wish to remain in an active status. Federal regulations do not allow for extensions to be given on the expiration date.

If we can be of further assistance, please call the IRB office at (405) 325-8110 or send an email to irb@ou.edu.

Cordially

Aimee Franklin, Ph. D
Vice Chair, Institutional Review Board

701-A-1

University of Oklahoma
Institutional Review Board
Informed Consent to Participate in a Research Study

Project Title: A Regional Study of Biological Evolution Literacy in Secondary Schools
Principal Investigator: Tony Yates
Department: Instructional Leadership and Academic Curriculum

You are being asked to volunteer for this research study. This study is being conducted at the high school where you are employed. You were selected as a possible participant because you are a current life science teacher employed by an Oklahoma high school who will be teaching at least one section of Biology I during the 2010-2011 academic year. You were selected as a possible participant for this study by direct contact with your school's science chair. Please read this form and ask any questions that you may have before agreeing to take part in this study.

Purpose of the Research Study

The purpose of this study is to identify the level of biological evolution literacy in Oklahoma secondary school life science classrooms.

Number of Participants

Approximately 50-350 people will take part in this study.

Procedures

If you agree to be in this study, you will be asked to complete a survey and provide contact information for follow up activities.

Length of Participation

Time required to complete the contact information and survey will be approximately 30 minutes.

This study has the following risks:

There are no risks associated with this study. Participants may withdraw from the study at any time. Some research designs require that the full intent of the study not be explained prior to participation.

Benefits of being in the study are

None

Confidentiality

In published reports, there will be no information included that will make it possible to identify you without your permission. Research records will be stored securely and only approved researchers will have access to the records.

There are organizations that may inspect and/or copy your research records for quality assurance and data analysis. These organizations include the OU Institutional Review Board.

Compensation

You will not be reimbursed for your time and participation in this study.

Voluntary Nature of the Study

Participation in this study is voluntary. If you withdraw or decline participation, you will not be penalized or lose benefits or services unrelated to the study. If you decide to participate, you may decline to answer any question and may choose to withdraw at any time.

Contacts and Questions

If you have concerns or complaints about the research, the researcher conducting this study can be contacted via telephone at (405) 878.2098 or (405) 220.4139, or via e-mail at tony.yates@okbu.edu. The researcher's advisor can be contacted via phone at (405) 325-1498 or 325-5723, or via e-mail at eamarek@ou.edu.

Contact the researcher(s) if you have questions or if you have experienced a research-related injury.

If you have any questions about your rights as a research participant, concerns, or complaints about the research and wish to talk to someone other than individuals on the research team or if you cannot reach the research team, you may contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu.

You will be given a copy of this information to keep for your records. If you are not given a copy of this consent form, please request one.

Statement of Consent

I have read the above information. I have asked questions and have received satisfactory answers. I consent to participate in the study.

Signature Date

APPROVED
APR 19 2010
OU NC IRB

APPROVAL
APR 18 2011
EXPIRES