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Is Oklahoma really OK? A regional study of the prevalence of biological evolution-related misconceptions held by introductory biology teachers

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Abstract

Background: 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.

Methods: Seventy-six teachers who taught at least one section of Biology I during the 2010 to 2011 academic year in one of 71 Oklahoma public high schools served as this study's unit of analysis. The *Biological Evolution Literacy Survey*, which possesses 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.

Results: 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.

Conclusions: Biological evolution-related misconceptions are prevalent within Oklahoma's introductory biology teachers. 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).

Background

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

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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) 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).

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 1989; Moore 2000; National Academy of Sciences 1999; National Association of Biology Teachers 2008; National Research Council 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 Academy of Sciences 2008). Scientific organizations, including the National Academy of Sciences (1999), National Association of Biology Teachers (2008), American Association for the Advancement of Science (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 US adults accepting the idea of evolution has declined (Miller et al. 2006). Miller (2006) indicates that probable reasons for society's low acceptance of evolution include the widespread lack of understanding of biological concepts. 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 *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 and most teachers experience the same levels of science education as does the general public, teachers too are likely to hold biological evolution misconceptions. Across the nation, this hypothesis is supported, because 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); only 57% of biology teachers nationwide consider evolution to be a unifying theme in biology (Moore 2000); and 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. Because 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.

To assess public high school introductory biology teachers' conceptions and knowledge structure about biological evolution, we surveyed such teachers 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 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 with similar studies that 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 to 2011 academic year. Therefore, it was expected that participants possessed 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 *Priority Academic Student Skills (PASS*; Oklahoma State Department of Education 2013) were developed in 1993 based on the *National Science Education Standards* (National Research Council 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 (National Research Council 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 2008–2009* (Oklahoma State Department of Education 2009c) 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 men and 36 women) employed on a full-time basis during the 2010 to 2011 academic year by 71 (15.0%) of the 474 public high schools Oklahoma State Department of Education (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 that 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 ninth or tenth grade) during the 2010 to 2011 academic year.

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 science education, non-biology science or non-science 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. 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.

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 was composed of two sections. The first section requested demographic data that 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/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

Table 1 Teacher profile

Demographic variable	Variables	*n*	%[a]	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
	Non-biology science	18	23.7	90.22
	Science education	22	28.9	90.04
	Non-science	12	15.8	82.75
	No response	2	2.6	-
Years' teaching experience	0 to 5	14	18.4	89.07
	6 to 10	13	17.1	91.69
	11 to 15	14	18.4	90.71
	16 to 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_{b}
	Average	21	27.6	83.95
	Fair	4	5.3	80.75_{b}
	Poor	0	0.0	-
Teaching hours dedicated	0	2	2.6	77.00_{cd}
	1 to 5	27	35.5	86.56
	6 to 10	19	25.0	89.84_{c}
	11 to 15	13	17.1	89.08
	>15	14	18.4	99.86_{d}
Average daily membership	4451.85 to 485.57	14	10.0	95.36
	482.10 to 242.95	18	23.3	91.78
	242.30 to 134.10	9	16.7	93.22
	132.10 to 78.11	11	18.3	91.55
	77.73 to 14.85	13	21.7	88.54
	No response	11	14.5	-
Urban-centric classification	City	2	3.3	103.50
	Suburban	3	5.0	96.33
	Town	19	26.7	92.53
	Rural	41	65.0	90.98
	No response	11	14.5	-

Maximum index score is 115. Those BEL-MIS possessing the same subscript are significantly different at $P < 0.05$. [a]Percentages may not total 100 due to rounding. BEL-MIS, Biological Evolution Literacy Survey mean index score.

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. Answers to statements indicative of a low acceptance of an evolution concept (high acceptance of the associated misconception) received low scores and answers to statements indicative of a high acceptance of an evolution concept (nonacceptance of misconception) received 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/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. A score of 115 represented the highest level of understanding of those evolutionary concepts revealed by the BEL Survey coupled with a lack of associated misconceptions. 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 *et al*. 1994; Wescott and Cunningham 2005; Wilson 2001). These misconception categories included: (a) science, scientific methodology and terminology; (b) intentionality of evolution; (c) nature of evolution; (d) mechanisms of evolution; and (e) evidence supporting evolution. Five biological evolution-related misconception statements were identified or developed for the science, scientific methodology and terminology; intentionality of evolution; and mechanisms of evolution categories. Four statements were identified or developed for the nature of evolution and evidence supporting evolution categories. The resulting 23 statements were subsequently included in the BEL Survey (see Table 2) 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 (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 and the BEL Survey mean index score (BEL-MIS) for members of each identified criteria. Male participants comprised 52.6% (n = 40) and female, 47.4% (n = 36) of the total. All participants possessed a minimum bachelor's degree, 34.2% (n = 26) held terminal master's degrees and 3.9% (n = 3) had doctorate degrees. Bachelor's degree majors were fairly evenly distributed among biology (28.9%, n = 22), science education (28.9%, n = 22), and non-biology science degrees (23.7%, n = 18), whereas only 15.8% (n = 12) of participants possessed non-science 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% (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) whereas 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) whereas only 5.3% (n = 4) described their knowledge level to be fair or poor. 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 did not decrease by more than 0.014, thus maintaining the survey's internal reliability.

Significant differences

Chi-square statistics were used to identify the existence of statistically significant differences (P <0.05) among variables related to the 71 public high schools employing the study's teacher participants and the 474 public high schools located within the study area (see Table 3). A comparison between the two sets of schools focused on two variables: distribution of student ADM (Institute of Education Sciences National Center for Education Statistics 2010a); and urban-centric classification (Institute

Table 2 Biological evolution literacy survey statement percent teacher response

#	Category	Statement	Teacher response (%)[a]					
			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'.[b]	*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.[b]	*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.[b]	*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.[b]	*9.2*	*19.7*	15.8	53.9	1.3	0.0
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.[c]	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'.[c]	*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.[b]	*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. [b]	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.[b]	*9.2*	*15.8*	7.9	59.2	6.6	1.3
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

Italicized data indicate percentage of participants accepting the statement-related misconception. [a]Percent response may not total 100.0% due to rounding. [b]Statement adapted from Cunningham and Wescott (2009). [c]Statement taken directly from Cunningham and Wescott (2009). 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.

of Education Sciences National Center for Education Statistics 2010b). No statistically significant differences were revealed between the two high school groups for either ADM distribution (χ^2 (4, n = 71) = 1.38, P >0.05) or urban-centric classification (χ^2 (3, n = 71) = 7.05, P >0.05). 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 with the total number of public high schools (n = 474) located within the study area.

Independent samples t-tests and one-way analysis of variance (ANOVA) were employed to determine if significant differences (P <0.05) existed between participants' BEL-MIS when related to specific group variables. Group variables analyzed included gender, years of teaching experience, terminal degree, degree major, emphasis placed on evolution in teachers' college courses, self-rating of biological evolution knowledge, hours dedicated to the teaching of biological evolution in a single Biology I course, 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 mean index score and male participants (n = 40) produced a mean index score of 87.48. Although women did average 5.91 index points (6.3%) higher than their male counterparts, the difference was not statistically significant (t(74) = 1.71, P = 0.42).

Table 3 Public high school profile

Demographic variable	Variable range	Percentage of high schools	
		Participants (*n* =71)	Study area (*n* = 474)
Average daily membership[a]	4451.85 to 485.57	20.0	20.0
	482.10 to 242.95	23.3	20.0
	242.30 to 134.10	16.7	20.0
	132.10 to 78.11	18.3	20.0
	77.73 to 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

Participants are high schools that employed study participants. Study area indicates the total number of high schools within the study area. For all results, $P > 0.05$ therefore differences were nonsignificant. [a]Average daily membership 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 (Institute of Education Sciences National Center for Education Statistics 2010a).
[b]Urban-centric classification (Institute of Education Sciences National Center for Education Statistics 2010b).

BEL-MIS were calculated based on participants' schools of employment urban-centric classification. No significant differences ($P < 0.05$) in participants' BEL-MIS were identified between the four urban-centric classifications ($F(3, 61) = 0.58$, $P = 0.63$). However, a trend was revealed showing a consistent increase in teachers' BEL-MIS when moving 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 ($n = 2$) schools. 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 ($F(4,60) = 0.38$, $P = 0.82$). 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 to 485.57) whereas 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 to 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 ($P < 0.05$) between participants' BEL-MIS based on the terminal degree classes ($F(2, 73) = 0.54$, $P = 0.58$). 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 ($F(3,70) = 1.85$, $P = 0.15$) a relatively low nonsignificant difference ($P = 0.10$) was discovered between the BEL-MIS of those participants possessing non-science 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 *et al*. (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 women (mean= 93.39, SD = 15.29) and men (mean = 87.48, SD = 14.87). Whereas 33.3% ($n = 12$) of women held biology bachelor's degrees and 13.9% ($n = 5$) held non-science bachelor's degrees, 30.0% ($n = 12$) of men possessed biology bachelor's degrees and 20.0% ($n = 8$) held non-science 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 to 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, because those participants with 0 to 5 years of experience ($n = 14$) produced an 89.07 BEL-MIS and 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 in this category were revealed ($F(3, 71) = 1.48$, $P = 0.23$), 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 ($P < 0.05$) was revealed between the BEL-MIS of those participants who dedicated 0 hours of evolution instruction (mean = 77.00, SD = 0.0, $n = 2$) and those who dedicated 6 to 10 hours (mean = 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 (mean = 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. ('Poor' was a fifth survey choice but not selected by any participant.) ANOVA revealed a significance difference in BEL-MIS among the biological evolution knowledge self-rating descriptor groups ($F(3, 72) = 2.81$, $P = 0.046$). Specifically, a significant difference ($P = 0.04$) was determined between the BEL-MIS for participants who indicated a good biological evolution knowledge rating (mean = 94.35, SD = 12.90, $n = 34$) versus those who indicated a fair knowledge rating (mean = 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 (mean = 92.18, SD = 20.34) than did those who identified themselves as possessing a good knowledge (mean = 94.35, SD = 12.90, $n = 34$).

Science, scientific methodology and terminology

Table 2 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. The combined pair of percent responses in the adjacent non-highlighted 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 addressed 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"') revealed that 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 ($r(71) = 0.49$, $P < 0.01$). However, only 67.1% ($n = 49$) of participants who completed both statements 1 and 5 ($n = 73$) understand the term 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. Although 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).

Table 4 compares participants' interaction statement responses to those of a specified statement. A, agreed; D,

Table 4 Interaction between teacher responses to selected BEL survey statements

Statement	Interaction statement	Agree with statement[a]			Disagree with statement[a]			Undecided about statement[a]		
		A%	%D	%U	%A	%D	%U	%A	%D	%U
Science, scientific method 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
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

disagreed; U, undecided. Example: Of those participants who agreed with statement 1, 35.7% disagreed with statement 5. [a]Response percentages may not total 100 due to rounding.

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, with 26.3% (n = 20) revealing 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, $r(74) = 0.60$, $P < 0.01$), 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. Although 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 but 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

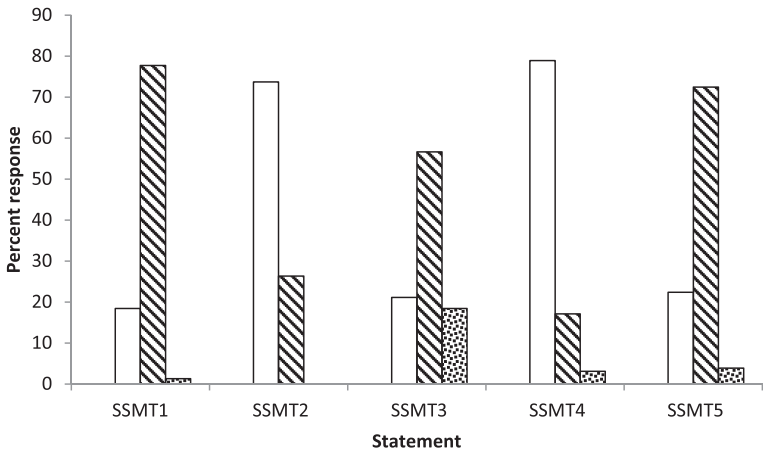

Figure 1 Percent response to science, scientific method and terminology statements. Clear bar = strongly agree/somewhat agree; diagonal bar = strongly disagree/somewhat disagree; dotted bar = undecided/never heard of it.

for evolution to have occurred. This finding nearly replicates that of Berkman et al., who in a2008 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. It is encouraging that 56.6% (n = 43) participants 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 because 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. Although 50.0% of participants (n = 35) who completed all five statements (n = 70) lacked 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 misconception 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 to achieve goals. Consequently, there seems to be a powerful

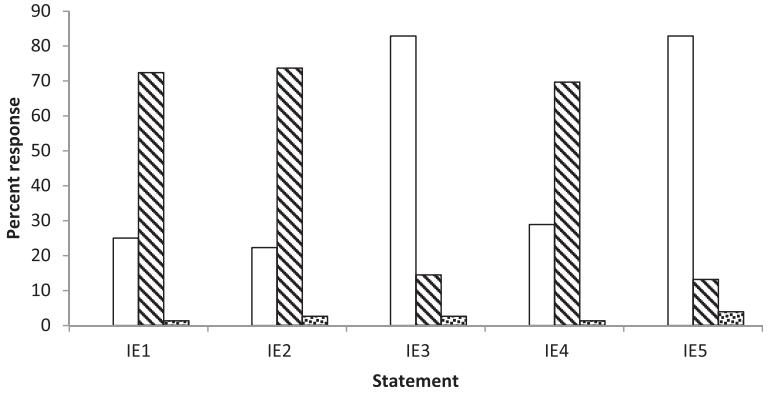

Figure 2 Percent response to intentionality of evolution statements. Clear *bar* = strongly agree/somewhat agree; diagonal bar = strongly disagree/somewhat disagree; dotted bar = undecided/never heard of it.

psychological bias toward imparting purpose or function to nonhuman objects, processes and behaviors. Statements 6 through 10 addressed 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 understand that the process of evolution does not always result in improvement. However, 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 whereas 22.3% (n = 17) agreed, indicating that the majority of participants understand that evolution is not based on need. A large positive correlation ($r(72) = 0.378$, $P < 0.01$) 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. Although 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 ($r(73) = 0.35$, $P < 0.01$) existed 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 possessed contradictory conceptions in regard to the intentionality of evolution as related to these statements.

Statement 10 ('Evolution cannot cause an organism's traits to change within its lifetime') produced a majority 82.9% (n = 63) agreement among participants, with 13.2% (n = 10) in disagreement, and 3.9% (n = 3) undecided. 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 ($r(73) = -0.42$, $P < 0.01$). This revealed that 65.3% (n = 49) of those participants who addressed both statements 10 and 7 (n = 75) correctly understood 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) disagreed with statement 10. Although 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 ($r(74) = 0.44$, $P < 0.01$) existed 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. These four 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, four 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.

Although 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: (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). 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 1987 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), and 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.

Although 43.2% (n = 32) of participants who completed all five statements (n = 74) lacked 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 ($r(74) = 0.36$, $P < 0.01$) between statements 11 (positive) and 13 (negative) reveals much diversity of opinion among participants, because 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 presented 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 because there is probably no other misconception which better indicates a lack of understanding of evolution than the belief that evolution proceeds by random chance (Isaak 2003). With the environment

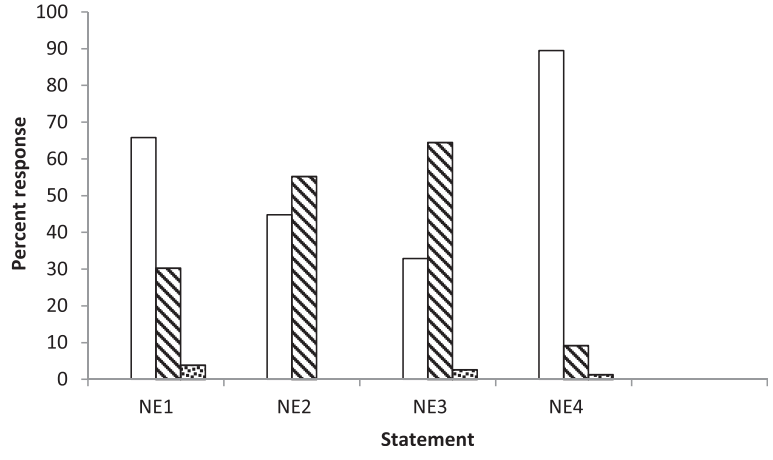

Figure 3 Percent response to nature of evolution statements. Clear bar = strongly agree/somewhat agree; diagonal *bar* = strongly disagree/somewhat disagree; dotted bar = undecided/never heard of it.

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' (Dawkins 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 with 9.2% (n = 7) disagreeing. 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 and 4.0% (n = 3) revealed misconceptions associated with both statements 11 and 14. Analysis revealed 57.9% of participants (n = 44) held 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 understood 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 assigns the ability to adapt to their environments to individual organisms whereas 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 ($r(27) = -0.09$, $P < 0.41$).

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, whereas 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.

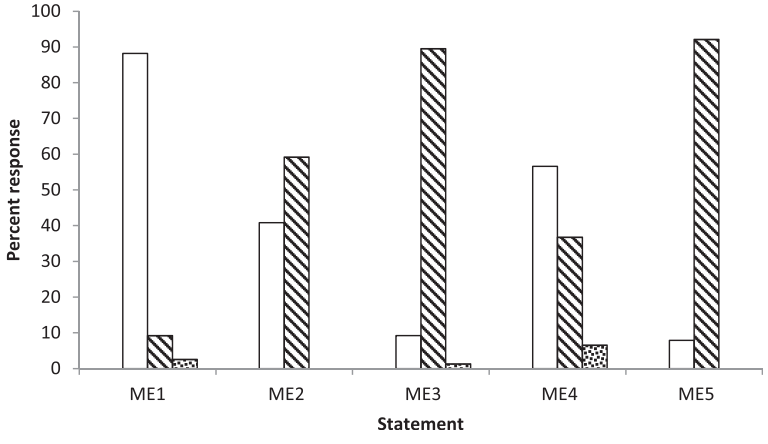

Figure 4 Percent response to mechanisms of evolution statements. Clear bar = strongly agree/somewhat agree; diagonal bar = strongly disagree/somewhat disagree; dotted bar = undecided/never heard of it.

Mechanisms of evolution

Statements 15 through 19 addressed 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 whereas 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 ($r(74) = -0.45$, $P < 0.01$). Analysis revealed that 3.9% (n = 3) of participants disagreed with statement 15 while simultaneously agreeing with statement 19. Although 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 that 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 understood 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. Although these individuals inaccurately view evolution as a process that 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) affirming the statement and 59.2% (n = 45) selecting the misconception. For those individuals agreeing with statement 15 (n = 67), 62.7% (n = 42) disagreed with statement 16, resulting in a small negative correlation ($r(74) = -0.23$, $P < 0.05$). 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, 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). 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.* 2002) as opposed to Darwin's definition: '[The] preservation of favourable individual differences and variations, and the destruction of those which are injurious' (Darwin 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 whereas 9.2% (n = 7) voiced their approval for the statement, revealing their misconception. A medium negative correlation ($r(74) = -0.27$, $P < 0.05$) 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 the 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 whereas 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 ($r(74)$ = 0.41, P <0.01). 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) disagreed with statement 18. This indicates that these individuals understand that variation within a species is important for evolution to occur but 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, who 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. Although 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 addressed 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) study of Indiana public high school biology teachers (n = 522), which 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 versus n = 552) or the statement terminology, that is, evidence versus 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 ($r(73)$ = –0.26, P <0.05) was produced between statements 20 and 22 with 81.2%

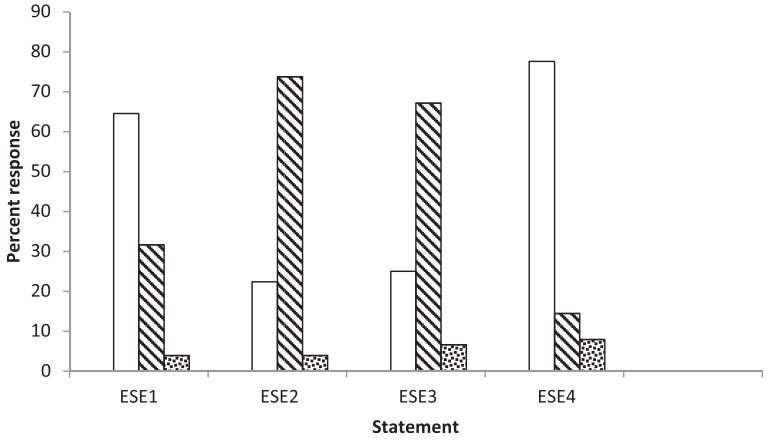

Figure 5 Percent response to evidence supporting evolution statements. Clear bar = strongly agree/somewhat agree; diagonal bar = strongly disagree/somewhat disagree; dotted bar = undecided/never heard of it.

(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: 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) agreed 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 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 ($r(74) = 0.47$, $P < 0.01$) 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 ($r(74) = 0.61$, $P < 0.01$) was discovered between participants' responses to statements 20 and 4, with 63.2% (n = 48) agreeing with both positive statements and 15.8% (n = 12) disagreeing 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 eight 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.

Although 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 ($r(74) = -0.18$, $P = 0.13$) 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 disagreed with statement 20 (n = 24), 41.7% (n = 10) agreed 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 whereas 20.4% (n = 10) either disagreed (12.2%, n = 6) or were undecided or never heard of it (8.2%, n = 4). Thus, analysis revealed a medium positive correlation ($r(74) = 0.26$, $P < 0.05$) between statements 20 and 23. It is interesting that six

participants who correctly indicated 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 believed 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 because participants earned a meager 70.7% mean rate of understanding in response to the four evidence supporting evolution statements contained within the BEL Survey while producing a 23.4% misconception rate. Although 41.3% (n = 31) of participants who completed all four statements (n = 75) lacked 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, 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, and 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 ≥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 (statement 18, 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 *et al*. 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 that, 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.

Abbreviations

ADM: average daily membership; ANOVA: analysis of variance; BEL: Biological Evolution Literacy; MIS: mean index score; PASS: Priority Academic Student Skills; SD: standard deviation.

Authors' contributions

TBY devised the research problem, drafted the BEL Survey, carried out and interpreted the research results. EAM contributed to the conception and design of the research project and critically revised the manuscript for intellectual content. All authors read and approved the final manuscript.

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