Academic Preparation in Biology and Advocacy for Teaching Evolution: Biology Versus Non-Biology Teachers

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ABSTRACT: Despite considerable focus on evolution knowledge–belief relationships, little research has targeted populations with strong content backgrounds, such as undergraduate degrees in biology. This study (1) measured precertified biology and non-biology teachers' ($n = 167$) knowledge of evolution and the nature of science; (2) quantified teacher preferences for the teaching of creationism in schools; (3) examined the associations among knowledge and belief variables; and (4) contrasted the knowledge and beliefs of prospective biology teachers with those of non-biology teachers. Methodologically, teacher knowledge was quantified by using three measures and studied in relation to certification area, self-reported religiosity, personal conflict concerning science and religion, and completion of an evolution course. We found (1) generally low levels of knowledge of evolution and the nature of science—and high misconception magnitudes—in both biology and non-biology teachers; (2) comparable antievolutionary positions in biology and non-biology

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teachers: nearly half of the teachers in both groups advocated for the inclusion of creationism in school; (3) weak association between knowledge and preference/belief variables; and (4) no difference in preference for teaching creationism between those teachers who had taken an evolution course and those who had not. Overall, biology and non-biology teachers were found to display "mixed" and "novice naturalistic" evolutionary reasoning patterns. *Sci Ed* 1–25, 2009

INTRODUCTION

Biologists consider evolution to be the central, unifying theme of their field, and many science and science education associations in the United States have released position statements expressing their unequivocal support for the teaching of evolution in high school science classrooms (Dobzhansky, 1973; National Academy of Science, 1998; National Association of Biology Teachers, 2002; National Science Teachers Association, 1997). The National Science Education Standards are unambiguous in their recognition of evolution and natural selection as core science learning goals (Bybee, 2003; National Research Council, 1996). Nevertheless, large percentages of science teachers—close to a majority in many samples—reject evolutionary theory and support the teaching of antievolutionary ideas in schools (Nehm & Schonfeld, 2007). Thus, despite overwhelming agreement from the scientific and science education communities, evolution remains a problematic subject for many science teachers.

The discordance between the views of scientists and teachers, coupled with the perceived "controversial" nature of evolution by the general public, has led to an explosion of scholarly research and public debate concerning the teaching and learning of evolution in the United States and elsewhere (Deniz, Donnelly, & Yilmaz, 2008; Hokayem & BouJaoude, 2008; Nehm & Schonfeld, 2008). Indeed, the beliefs, attitudes, and knowledge of many different populations have been investigated; all are characterized by low levels of understanding and acceptance of evolution, as well as the occurrence of many misconceptions (Bishop & Anderson, 1990; Brooks, 2001; Brumby, 1979; Clough & Wood-Robinson, 1985; Dant, 1990; Dagher & BouJaoude, 1997; Deadman & Kelly, 1978; Nehm & Schonfeld, 2007).

Numerous additional studies have also explored contextual factors that complicate the effective teaching of evolution in schools (Donnelly & Boone, 2007). Teachers often do not want to teach evolution (Aguillard, 1998; Eve & Dunn, 1990; Shankar & Skoog, 1993), do not feel adequately prepared to teach it (Aguillard, 1999; Griffith & Brem, 2004), and do not understand the legal precedents associated with evolution education (Moore, 2004). Many communities, school boards, and parents challenge teachers when they follow state and national standards and teach evolution (Chuang, 2003; Tatina, 1989; Van Koevering & Stiehl, 1989). These and other contextual factors are not surprisingly associated with teachers' emotional stress and negative perceptions regarding evolution (Brem, Ranney, & Schindel, 2003; Griffith & Brem, 2004). The teaching of evolution is a significant challenge for many science teachers.

A question that has received increasing attention is whether knowledge and belief are meaningfully associated constructs within particular subject matter domains (for reviews, see Deniz et al., 2008; Limon, 2003; Nehm & Schonfeld, 2007; Sinatra, Southerland, McConaughy, & Demastes, 2003). For nearly 20 years science educators have conducted empirical studies exploring the relationships between evolutionary knowledge and belief in different populations (Bishop & Anderson, 1990; Demastes, Settlage, & Good, 1995; Deniz et al., 2008; Dole, Sinatra, & Reynolds, 1991; Ingram & Nelson, 2006; Lawson & Worsnop, 1992; Lord & Marino, 1993; Nehm & Sheppard, 2004; Nehm & Schonfeld, 2007; Southerland & Sinatra, 2003). The vast majority of these studies have found that knowledge and belief are weakly associated constructs (Southerland & Sinatra, 2003) though notably, Lawson and Worsnop (1992) found that high school biology students' knowledge of evolution was significantly related to their belief in evolution. In knowledge domains other than evolution, research supports the generalization that knowledge and belief are loosely associated constructs (Brewer & Chinn, 1991; Nehm & Schonfeld, 2007).

Empirical studies of knowledge and belief have usually examined scientifically less sophisticated populations, such as high school students and college nonmajors (e.g., Bishop & Anderson, 1990; Lawson & Worsnop, 1992; Southerland & Sinatra, 2003) despite suggestions in the literature that domain-specific knowledge plays a central role in conceptual change (Limon, 2003). Indeed, very little research has focused on knowledge–belief relationships in populations with more extensive subject matter preparation. It is possible that current generalizations may hold only at particular knowledge thresholds (Nehm & Schonfeld, 2007). Much more work, therefore, is needed to explore these relationships in samples that have received substantial academic preparation in biology—such as biology teachers.

Methodologically, studying biology teachers who have completed undergraduate majors in the life sciences is a direct and obvious approach for exploring putative associations among subject matter knowledge and belief (and/or advocacy). Broadening sampling strategies to include comparable cohorts of non-biology teachers should be informative. If subject matter knowledge is expected to impart (or be associated with) particular belief stances, then studies of groups that differ significantly in their subject matter knowledge should illuminate such relationships. This is the methodological strategy adopted in the present study—comparing the beliefs within a large group ($n = 167$) of teachers, between those with substantial academic preparation in biology (undergraduate degrees in the life sciences) and those lacking such preparation. Overall, the study explores what effect, if any, undergraduate biology (including evolution) coursework has imparted on the evolutionary beliefs of teachers.

Terms: Acceptance, Belief, and Knowledge

A significant challenge in research attending to knowledge–belief–acceptance interrelationships is the precise demarcation of such constructs—if such boundaries can be demonstrated to be theoretically justified and empirically defined. A burgeoning literature about these terms has focused on their theoretical, philosophical, and epistemological meanings, with minor agreement among authors (e.g., Alters, 1997; Chinn & Samarapungavan, 2001; Coburn, 1994, 2004; Cooper, 2001; Davson-Galle, 2004; Sinatra et al., 2003; Smith, 1994; Smith & Siegel, 2004; Southerland, 2000; Southerland & Sinatra, 2003; Southerland, Sinatra, & Matthews, 2001). Generally, "acceptance" is considered the recognition of a theory's validity through rational and systematic evaluation of evidence, whereas belief is considered the recognition of a theory's validity, using personal conviction, opinion, and extrarational criteria (Smith, 1994; Southerland & Sinatra, 2003).

Such solid distinctions dissolve in many research and classroom contexts because research participants are (a) unaware of the differences in the academic (vs. colloquial) meanings of these terms; (b) unsure of the generative process that produced their ideational networks; or (c) unlikely to recognize that their own beliefs are irrational or not based on evidence—even if this is the case—thus rendering the distinctions between belief and acceptance meaningless in self-reports. Arguably, few individuals are sufficiently metacognitive to be aware of the epistemic and ideational foundations of their beliefs, which motivates the question of whether it is possible for a researcher to determine how, epistemologically, individuals have arrived at their conclusions. It may be likely that practicing scientists *believe*, rather than *accept*, many scientific concepts. One could extend this line of reasoning and argue that belief is a central and common descriptive reality in *all* scientific endeavors; no scientist has the specialized knowledge and access to experimental apparatus, data, or materials to rationally and systematically determine the validity of most (if not all) scientific ideas outside of his or her discipline. It is likely, then, that scientists believe rather than accept much of their scientific knowledge, even though they would undoubtedly prefer to view such knowledge as acquired through the systematic and rational evaluation of evidence (National Academy of Science, 1998). In the present study, we therefore consider *belief* and *acceptance* to be empirically interchangeable terms referring to an individual's personal validity judgments. Alternative frameworks are summarized in Jones and Carter (2007, Table 35.1) and Southerland and Sinatra (2003).

As noted by Abell (2007), distinctions between knowledge (e.g., subject matter knowledge) and belief are difficult, as the terms have been defined in various ways by the science education community (Fenstermacher, 1994). Many "knowledge" definitions encompass notions of "justified true belief" (Southerland & Sinatra, 2003). Justification of belief may be produced via rational appraisal or empirical tests of correspondence with "reality." Beliefs, on the other hand, may be considered to be a separate class of ideation, and one held to different epistemic standards than knowledge. Specifically, beliefs are considered subjective personal truths that are inherently excused of rational evaluation and correspondence tests with "reality" (Southerland & Sinatra, 2003).

The distinctions discussed above are not unproblematic. Lawson and Weser (1990), for example, in their study of knowledge and beliefs relating to evolution, defined the concepts of orthogenesis, nonemergentism, and vitalism as "beliefs"; interestingly, all of these concepts have at various periods in history been considered to be truthful and accurate "knowledge" by the scientific community. Thus, adhering to Lawson and Weser's distinctions, it appears that "knowledge" constructs may be reclassified into "belief" categories when worldview changes or paradigm shifts occur (Thagard, 1992). Such views align with contemporary notions of scientific knowledge as being dynamic, changing, and tentative (McComas, 1998). In the present study, we define and generate measures of "knowledge" by determining the degree of correspondence of participants' written responses to the information that the scientific community currently considers to have passed rational evaluation and empirical tests of correspondence to reality.

Hypotheses

Our study tests three hypotheses about teacher knowledge of evolution and belief/acceptance of evolution:

1. Biology teachers harbor greater funds of subject matter knowledge of evolution and the nature of science, and possess fewer misconceptions, than comparable samples of non-biology teachers.
2. Biology teachers display greater magnitudes of belief/acceptance of evolution and preference that students be taught evolution exclusively in school than non-biology teachers.
3. Knowledge of evolution and the nature of science are significantly associated with belief/acceptance of evolution.

Data Collection, Variables, and Methods of Analysis

Our survey instrument was administered and completed by 167 precertified science teachers (98% participation rate) actively enrolled in teacher certification programs at a public and a private university in New York City. The prospective teachers were in the process of obtaining certification in the fields of secondary biology, chemistry, physics, earth science, or middle school/elementary education. It is worth noting that due to teacher shortages in New York City, teachers who are enrolled in certification programs (i.e., precertified) may be employed as full-time teachers (i.e., in-service). Nearly all participants were in-service (or practicing) teachers and all were precertified (that is, they lacked permanent New York State teacher certification credentials). The mean teaching experience for the sample was approximately 2 years (see below).

Teachers were from a range of ethnic and racial backgrounds. Although the majority was of White non-Hispanic origin, approximately 35% of the sample was Latino/a, Afro-Caribbean, and Asian (subgroup percentages were not collected). Teacher knowledge of and attitudes toward evolution and the nature of science (along with basic demographic information) were assessed using a paper and pencil instrument (for details, see Nehm & Sheppard, 2004; Nehm & Schonfeld, 2007). We briefly review the eight variables of interest in the present study. Additional information on the reliability and validity of these variables may be found in Nehm and Reilly (2007), Nehm and Schonfeld (2007, 2008), and Nehm and Sheppard (2004).

1. *Conflict*. Teachers were asked to self-report whether they were conflicted about their scientific and religious beliefs by designating which of the following statements best applied to them: (a) "Evolutionary ideas are at odds or in conflict with my religious beliefs." Or (b) "Evolutionary ideas are NOT at odds or in conflict with my religious beliefs." The answers were coded as binary scores.
2. *Religiosity*. Teachers were asked to self-report their religiosity (see Nehm & Schonfeld, 2007). Teachers recorded which of four statements about religion best applied to them: (a) "I am not religious at all"; (b) "I am somewhat religious"; (c) "Religion is an important part of my life"; or (d) "Religion is a very important part of my life." The answers were coded as ranked ordinal scores (1–4) and in some cases were collapsed into a binary variable (low religiosity or high religiosity) to increase statistical power. An independent question about participant spirituality, administered in an isomorphic format, produced strong and significant correlations with *Religiosity* ($r = .88$, $p < .01$). This result lends credence to the interpretation that teachers' self-reported religiosity was valid.
3. *Evocourse*. To determine whether prior completion of an evolution course was associated with patterns documented in this study, teachers were asked to answer the following question: "Have you taken a college course primarily in biological evolution (yes or no)?" The answers were coded as binary scores.
4. *Key concepts* of natural selection (KC). Seven key concepts relating to natural selection were identified (Anderson, Fisher, & Norman, 2002; Mayr, 1982). The concepts included (a) the causes of phenotypic variation (e.g., mutation, recombination, sexual reproduction); (b) the heritability of phenotypic variation; (c) the reproductive potential of individuals; (d) limited resources, carrying capacity, or both; (e) competition or limited survival potential; (f) selective survival based on heritable traits; and (g) a change in the distribution of individuals with certain heritable traits. The presence or absence of these seven key concepts was noted in the teachers' essay responses to a slightly modified version (our modifications are contained in parentheses below) of Bishop and Anderson's (1990) extensively used essay question: "Cave salamanders (amphibian animals) are blind (they have eyes that are nonfunctional). How would a biologist explain how blind cave salamanders evolved from ancestors that had functional eyes and could see? Provide as detailed an answer as you can" (p. 418).

A coding rubric was developed, and teacher responses were scored such that the use of a key concept in their explanation of evolutionary change in salamanders counted as 1 point. Thus, an essay response that employed all seven key concepts received 7 points. Note that key concept repetition did not result in an increased score. The essays were blindly recoded by another scientist, using the same rubric to examine interrater reliability. Pearson correlation coefficients for key concepts between the two raters were statistically significant ($r = .89$, $p < .001$). Additional aspects of the coding and validity of this measure are discussed in Nehm and Schonfeld (2008).

5. *Misconceptions* about natural selection (MIS). A coding rubric containing commonly documented misconceptions was developed (e.g., mutations are caused primarily by mutagenic substances; needs cause evolutionary changes to take place; the use or disuse of traits explains their appearance/disappearance; and so forth (see Bishop & Anderson, 1990). Teacher responses were scored so that the use of an identifiable misconception in the evolutionary explanation counted as 1 point. Our rubric also permitted the coding of novel misconceptions not reported in the literature. There was no upper limit to the number of misconceptions that could be employed by teachers in the essays. The essays were blindly recoded by another scientist using the same rubric to examine interrater reliability. The Pearson correlation coefficient for the two raters' scores for key concepts was statistically significant ($r = .75$, $p = .008$). Additional aspects of the coding and validity of these and related measures are discussed in Nehm and Schonfeld (2008).
6. *ENOS-R* is a composite variable derived from 17 Likert-scale questions that are designed to measure teacher knowledge about the nature of science in relation to evolution (see Appendix for items and Nehm & Schonfeld (2007) for details on validity and reliability of the original ENOS variable). It is important to note that natural selection and evolution appear to be unrelated knowledge constructs; that is, knowledge of natural selection may be unassociated with knowledge of broader evolutionary concepts (e.g., extinction, the fossil record, deep time, phylogenetics, macroevolution, etc.). Hence, ENOS-R attempts to measure broader evolutionary concepts peripheral (but nonetheless related) to the core construct of natural selection. The ENOS-R items contain a variety of questions containing well-documented misconceptions about evolution and the nature of science, such as the notions that theories become laws when they are well supported, that dinosaurs and humans coexisted, and missing links are absent from the fossil record, among others (see Appendix). Participant ENOS-R scores could range from 0 to 85 (5 points for each correct item response). Cronbach's α for ENOS-R in the present study was an acceptable .73. In addition to previous studies of the validity and reliability of this measure (Nehm & Schonfeld, 2007), we explored the correlation of ENOS-R scores and MATE scores (Measure of Acceptance of the Theory of Evolution, developed by M. Rutledge) using a sample of 253 undergraduate biology majors in their first year. We found a strong and significant correlation between the ENOS-R and MATE measures ($r = .83$, $p < .01$). This provides additional evidence for the validity of the ENOS-R measure.
7. *Learn school*. In studies of science teachers, we argue that one of the most important questions to pose is whether teachers think evolution should be taught in schools. Our instrument assessed teacher preference for what students should learn in school, using the following question: "Which of the following would you prefer students to learn about in school? (a) Creationism (e.g., biblical creation, intelligent design, and/or creation science); (b) Evolution; or (c) Both creationism and evolution."

Answers were coded as nominal scores (1, 2, and 3), but collapsed (1 and 3) to increase statistical power in some analyses.

8. *Believe*. The instrument also assessed teacher preference for student belief about evolution, using the following question: "Which of the following would you personally prefer students to believe or accept? (a) Creationism (e.g., biblical creation, intelligent design, and/or creation science); (b) Evolution; or (c) Both creationism and evolution." Answers were coded as nominal scores (1, 2, and 3), but collapsed (1 and 3) to increase statistical power in some analyses.

In addition to calculating basic sample statistics for each variable, we used *t* tests (α designated a priori as .01) to compare knowledge variables between biology and non-biology teachers (e.g., ENOS-R, KC, and MIS) and Mann–Whitney *U* tests (the nonparametric equivalent of the *t* test) to compare attitude/belief measures (e.g., conflict, religiosity, learn, believe). We also compared knowledge variable measures between teachers who did and did not complete a college-level evolution class. In addition, we performed two-way ANOVAs to explore putative interaction effects among what we hypothesized were the most salient variables—learn school, *Certbio*, and knowledge variables (e.g., ENOS-R, KC, MIS). All of our analyses were performed in SPSS 16 (SPSS, Inc., Chicago, IL).

FINDINGS

Sample Characteristics of Biology and Non-Biology Teachers

The sample of 167 New York City teachers actively enrolled in teacher certification programs contained a larger number of biology than non-biology teachers (109 vs. 57, respectively). Nonresponses on individual items and subsequent composite measures produced sample sizes that did not always total 167. Overall, the two groups of teachers (biology and non-biology) were very similar in several respects: (1) their enrollment in teacher certification programs in New York City; (2) their average number of years of teaching experience; (3) their average self-reported religiosity; (4) the percentage who completed an evolution course; (5) the percentage lacking misconceptions; and (6) the percentage who preferred students to be taught and believe creationism. The two groups were most notably different in terms of the percentages who were conflicted about the relationship between science and religion (13% biology vs. 26% non-biology) and the average number of biology courses completed (nearly all biology teachers held undergraduate majors in a life science field).

An important question is whether our sample from New York City is representative of samples nationwide. Since the early 1940s, there have been an increasing number of studies about evolution–creation issues involving biology teachers from different states (Affannato, 1986; Burnett, 1941; Eglin, 1983; Fahrenwald, 1999; Firenze, 1998; Fisher, 1989; Groves, 1990; Johnson, 1991; Jorstad, 2002; Kraemer, 1995; Miller, 1990; Moore, 2008; Nehm & Schonfeld, 2007; Osif, 1997; Riddle, 1942; Shankar, 1989; Taylor, 1999; Trani, 2004; Troost, 1966; Zimmerman, 1987). These studies have investigated a wide range of topics that impact the teaching of evolution, including teacher beliefs, attitudes, religiosity, educational backgrounds, the emphasis placed on evolution in the curriculum, knowledge and understanding of the nature of science, and external pressure not to teach evolution. Although the results of these studies show a wide range of practices, beliefs, attitudes, and competencies, it is evident that regardless of location or population, the teaching of creationism or nonteaching of evolution is a concern for biology teachers (Moore & Kraemer, 2005). The results of the present study concur; we found that antievolutionary views and low magnitudes of evolutionary knowledge were just as pervasive in New York

City teachers as in other parts of the country. For example, 45% of biology teachers in our study preferred that students be taught some creationism (broadly defined), which is very similar to the findings in Kansas (Aldrich, 1991), Indiana (Troost, 1966), and slightly higher than the results in some national surveys (Eve & Dunn, 1990).

Knowledge of and Misconceptions About Evolution in Biology and Non-Biology Teachers

A priori, we hypothesized—and indeed hoped—that biology teachers in our sample would be shown to harbor greater funds of evolutionary knowledge than non-biology teachers. In general, we were not able to reject our hypothesis: ENOS-R and KC measures, which captured magnitudes of knowledge of evolution and the nature of science and knowledge of natural selection, respectively, were significantly different between biology and non-biology teachers (Table 1). It is important to note that the effect sizes of these differences were small. A comparison of the *types* of key concepts employed by biology and non-biology teachers in their Open Response Instrument (ORI) essay responses revealed similar explanatory models in the two groups. Specifically, the key concept of differential survival and reproduction was most commonly used by both groups of teachers whereas two other key concepts (biotic potential and competition) were almost never used (Figure 1). In summary, although biology teachers used a greater number of accurate key concepts in their evolutionary explanations, the key concepts that they used were not of a different sort than those used by non-biology teachers.

Unlike the results for KC, our analyses of MIS did *not* differ significantly between groups (Table 1). Biology and non-biology teachers on average used one misconception per essay response in their explanations of evolutionary change (Figure 1). In addition, like our results for KC, the *types* of misconceptions captured in teacher responses did not differ appreciably between the biology and non-biology groups (Figure 1). For example, causal explanations relating to organismal "needs" or environmental changes as drivers of evolutionary change comprised 25% of all misconceptions. In addition, for the "salamander" essay question (see data collection), the notion that other senses compensated for blindness, and that such sensory compensation was passed on to offspring, was the most commonly

TABLE 1
Statistical Comparisons Between Biology and Non-Biology Teachers in Terms of Knowledge Variables (i.e., ENOS-R, KC, and MIS) and Demographic and Belief Variables (i.e., Religiosity, Believe, Learn School, and Conflict)

Variable	*t*	*df*	Significance
Evoclass	−0.596	162.000	0.552
KC	−4.318	164.000	0.000**
MIS	−0.812	134.332	0.418
	U	*z*	Significance
ENOS	1927.500	−2.695	0.007**
Religiosity	2951.000	−0.416	0.685
Spirituality	2844.500	−0.817	0.414
Conflict	2565.000	−2.137	0.033*
Learn	3002.500	−0.075	0.941
Believe	2662.000	−0.723	0.470

*$p < .05$; **$p < .01$.

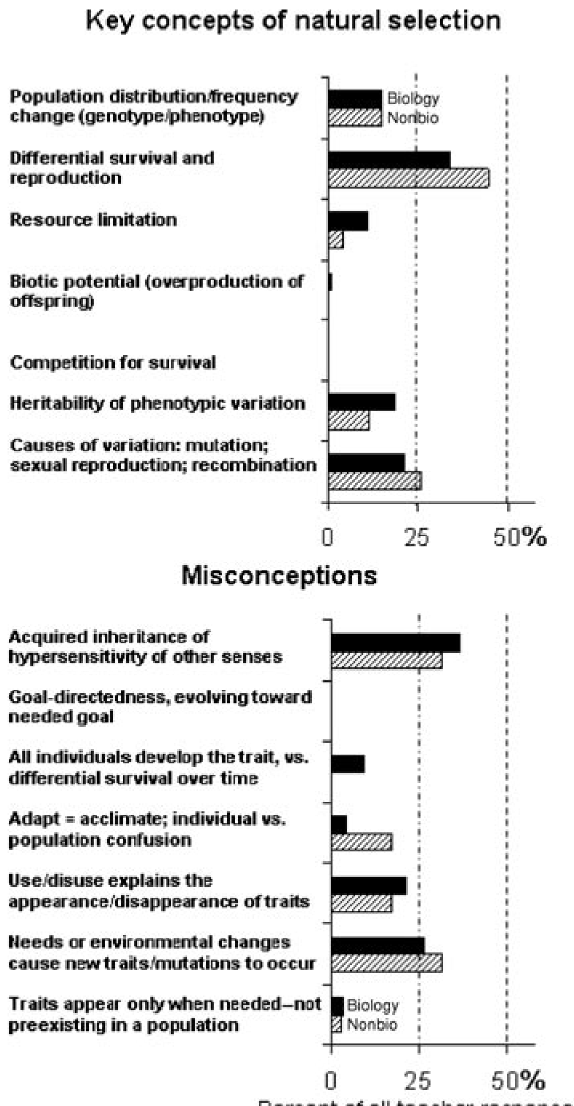

Figure 1. Natural selection knowledge and misconceptions in biology and non-biology teachers.

used misconception (Figure 1). Thus, despite greater knowledge concerning some aspects of evolution, the nature of science, and natural selection, both biology and non-biology teachers harbored many similar misconception frequencies as well as misconceptions of the same type. Finally, we did not discover any misconceptions in our sample that have not been reported in the literature previously (Nehm & Reilly, 2007; Nehm & Schonfeld, 2007, 2008).

The ENOS-R also revealed numerous misconceptions about evolution among biology and non-biology teachers, although biology teachers as a group displayed more accurate scores for all 17 items (Figure 2; Appendix). Less than half of the biology and non-biology teachers, for example, chose the correct response for ENOS-R item 2 (“After scientists determine that theories are well supported they refer to theories as facts”) and item 11 (“Fossil species have been found that are intermediate between humans and apes”). Nearly all of the other items displayed scores ranging from 50% to 75% correct. For example,

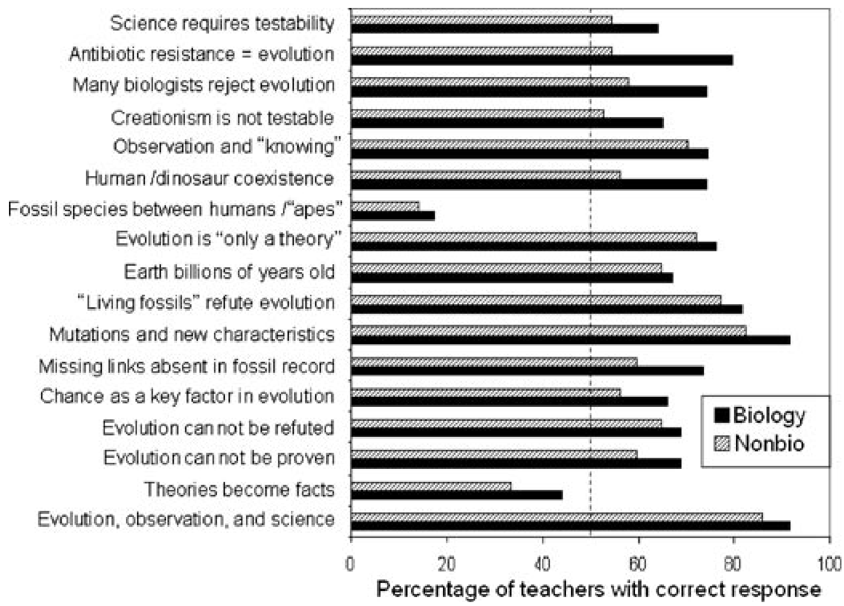

Figure 2. ENOS-R (evolution in relation to the nature of science) item responses for biology and non-biology teachers. Note that while biology teachers outperform non-biology teachers on every item, in many cases these differences are not significant.

34% of biology teachers disagreed with item 12 ("Radiometric dating of rocks indicates that the Earth is billions of years old"); nearly 25% of biology teachers agreed with item 13 ("Evolution is weaker than many other scientific concepts because it is only a theory"); 26% of biology teachers agreed with item 12 ("The survival of early humans was difficult because of predatory [carnivorous] dinosaurs"); and 20% of biology teachers disagreed with item 16 ("The organisms that cause malaria, gonorrhea, and tuberculosis have become resistant to antibiotics. The biological cause of this resistance is evolution"). Thus, large numbers of New York City biology (and non-biology) teachers harbor misconceptions about the most basic aspects of evolution.

Evolution Course

Our sample of 167 teachers included many individuals who reported having completed a college-level course focused primarily on evolution (Table 1). The first question we addressed was whether those teachers who completed an evolution course displayed significantly different religiosities than those who did not. We found no significant difference ($\alpha = .01$) in religiosity between these two groups (Mann–Whitney $U = 2287$, $Z = -0.29$, $p = .77$). Likewise, we found no significant differences in any measured knowledge variable between the teachers who completed an evolution course and those who did not (i.e., ENOS-R, KC, and MIS). Finally, we found no differences between the two groups in terms of whether they personally preferred that students are taught creationism in school or personally believe creationism (learn school Mann–Whitney $U = 2158$, $Z = -0.59$, $p = .56$; believe Mann–Whitney $U = 2086$, $Z = -0.32$, $p = .75$). Overall, in our sample of teachers, prior completion of an evolution course was not associated with any significant differences in knowledge or belief variables.

Teachers' Acceptance of and Belief in Evolution

Intuitively one might hypothesize, as we did, that New York City biology teachers display greater magnitudes of acceptance of evolution than non-biology teachers, because (1) most biology teachers in New York are required to have significant academic preparation in the subject (typically a baccalaureate degree), the content of which is conceptually intertwined with evolutionary principles; (2) individuals who pursued a biology degree may be more likely to accept as valid the conceptual framework of their chosen discipline; and (3) individuals who do not accept or believe in evolution may be more likely to pursue other scientific (or nonscientific) disciplines. Nevertheless, our hypothesis was rejected; biology and non-biology teachers had comparable perspectives on the teaching of evolution in schools and comparable belief preferences for their students. A Mann–Whitney U test revealed that biology and non-biology teachers do not differ significantly in their responses to the learn school and believe variables (Table 1). Specifically, 45.0% of biology teachers and 45.6% of non-biology teachers preferred that children be *taught* some "creationism" in school (that is, either "creationism" alone or "creationism" combined with evolution). Likewise, 51.4% of biology teachers and 57.9% of non-biology teachers preferred that children believe some "creationism." (note: "creationism" was defined broadly, encompassing creationism, creation "science," and/or intelligent design). Overall, beliefs do not differ significantly between our samples of biology and non-biology teachers (Table 1).

Religiosity and Conflict

Religiosity is an important variable in studies of evolution education because many teachers are personally conflicted about the relationship between science and religion (Sinclair, Pendarvis, & Baldwin, 1997). Although only 18% of our overall sample self-reported being conflicted about the relationship between science and religion, more than twice as many non-biology teachers were conflicted as biology teachers (26.3% vs. 12.8%, respectively; Table 1). Interestingly, our samples of biology and non-biology teachers were almost equally represented by individuals of high religiosities (37.6% biology vs. 35.1% non-biology teachers; Table 1). Thus, although the frequencies of high religiosity did not differ between groups, many more non-biology teachers are conflicted about the relationship between science and religion. Unsurprisingly, the frequencies of teachers who self-reported being less religious were less conflicted (Figure 3). Mann–Whitney U tests also revealed significant differences between teacher conflict groups for ENOS-R, KC, learn school, and believe ($p < .001$ in all cases). Thus, conflict is more strongly associated with knowledge and belief differences than religiosity alone. This result demonstrates that religiosity per se is not the most salient descriptor of teacher concern with evolution; measures of self-perceived conflict are more significantly associated with measured knowledge differences. Overall the two constructs are related—twice as many teachers of high religiosities were conflicted about the relationship between science and religion than those of low religiosities (12.3% vs. 5.6%, respectively).

Reasoning Patterns

Evans (2005) delineated four broad categories of adult evolutionary reasoning patterns: (1) *informed naturalistic reasoners*: those who adopt Darwinian evolutionary explanations for the origin of species; (2) *novice naturalistic reasoners*: those who adopt natural (as opposed to supernatural) explanations, display little understanding of Darwinian evolutionary mechanisms, and employ naive-Darwinian concepts (e.g., inheritance of acquired

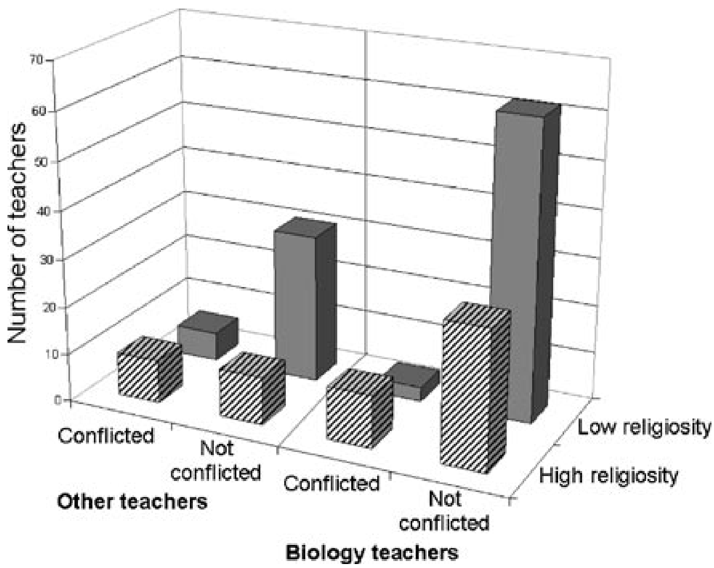

Figure 3. Relationship between religiosity and conflict in biology and non-biology teachers.

characteristics); (3) *creationist reasoners*: those who use supernatural explanations in their explanations of evolutionary events; and (4) *mixed reasoners*: those who employ more than one of the above strategies in combination. Although quite broad, we adopt Evans' (2005) framework for organizing the knowledge and belief data from our study. Specifically, we use ENOS-R items, essay responses, KC and MIS measures, and self-reported attitude scores to classify teachers from our sample into Evans' (2005) reasoning groups.

Our data suggest that New York City teachers harbor many different reasoning types, although most may be classified as mixed reasoners. Evidence of novice naturalistic reasoners, for example, is in great abundance in both biology and non-biology teachers' essays. Many of these essays contain pre-Darwinian ideas regarding the role of thoughts, needs, wants, and efforts as driving forces in evolutionary change (see also Figure 1). All of these misconceptions have been identified previously (Bishop & Anderson, 1990; Evans, 2005; Nehm & Schonfeld, 2008). We provide four examples of such novice naturalistic reasoning patterns in biology and non-biology teachers in response to the "Salamander" and "Cheetah" questions from the ORI (see Methods):

> When you use the organ more it will develop a better function because of the adaptation. If you do not use the organ it would be eliminated to its zero function as this kind of cave salamanders' [sic] eyes. In the cave, those animals do not require to survive with the eyes because it is dark inside the environment. So, the function of eyes is diminished from generation to generation until now.

(Participant H14: chemistry teacher; misconceptions: use and disuse drive evolutionary change; inheritance of acquired characteristics.)

> It is believed that when someone is blind their other senses become sharper. If for some reason the salamanders were forced to live in dark caves, the blind ones had a better chance of survival because while those that could see could not make use of their eyesight, the blind ones with their other sharper senses had probably an easier time at finding food.

(Participant H1: physics teacher; Misconceptions: hypertrophy of other senses and their acquisition by cave salamander descendants.)

> The need for cheetahs to run faster increased gradually throughout a period of time. Their bodies subsequently adapted to their need to run faster (maybe for food—prey) or in response to a predator.

(Participant H2: biology teacher; Misconceptions: needs drive evolutionary change; acclimation = adaptation.)

> The question is what triggered the mutation? Was it random or was there pressure from the environment for cheetahs to be able to run quickly?

(Participant H7: biology teacher; Misconception: environmental pressure may promote beneficial mutation.)

Creationist reasoners—those who use supernatural factors in their explanations of evolutionary events—are also in abundance in our sample as indicated by the high number of teachers who advocate for the teaching of creationism in schools, who prefer that children believe creationism, who disagree that the Earth is billions of years old, and who agree that dinosaurs and humans coexisted (Figure 2). Unambiguous classification of teachers as creationist reasoners is difficult, however, given that the "grain size" of our analysis may not be fine enough to separate such teachers from mixed reasoners (i.e., those who harbor both creationist *and* novice naturalistic notions of evolutionary change). Most distressingly, remarkably few of the teachers in our sample—biology or otherwise—may be classified as informed naturalistic reasoners, that is, those who adopt exclusively Darwinian evolutionary explanations. Pervasive misconceptions about natural selection, evolution, and/or the nature of science are common, allowing us able to identify with certainty only a minority (approximately 35%) of biology teachers as informed naturalistic reasoners. We find the majority of our science teachers are likely to be mixed reasoners, with *creationist reasoning* patterns present in many biology and non-biology teachers.

Associations Among Knowledge and Belief Variables

Spearman correlation coefficients quantified the associations among measured knowledge and belief variables (Table 2). The strongest correlation that we documented ($r = .50$, $p < .01$) was between learn school and believe; those teachers who preferred "creationism" to be taught in school tended to prefer that children also believe "creationism." A second strong suite of associations that we uncovered related to religiosity. Religiosity was significantly correlated with learn school ($r = -.40$; those teachers with stronger religiosities were more likely to prefer that children learn "creationism" in school), conflict ($r = -.31$; teachers with stronger religiosities tended to be more conflicted about the relationship between science and religion), and believe ($r = -.28$) (Table 2). Overall, religiosity and personal conflict were associated significantly with teaching preferences.

Knowledge variables demonstrated expected associations: MIS correlated negatively with ENOS-R ($r = -.24$, $p < .01$), as well as KC (key concepts of natural selection; $r = -.34$, $p < .01$), whereas KC and ENOS-R were positively and significantly associated ($r = .32$, $p < 0.01$). Knowledge and belief variables did display several significant, but weak, associations. ENOS-R and KC, for example, were significantly associated with learn school ($r = .33$ and .29, respectively); greater knowledge was associated with greater preference for the teaching of evolution in school, although this association explained

TABLE 2
Spearman Correlation Coefficients Among Knowledge and Attitude–Belief Variables

	EVOCLASS	ENOS-R	KC	MIS	Religiosity	Believe	Conflict	Learn School
ECOCLASS	1.000	.142	.033	−.175	−.023	.026	.095	.046
		.082	.678	.025	.770	.749	.231	.556
ENOS-R		1.000	.317**	−.242**	.214**	.216**	.311**	.328**
			.000	.003	.008	.008	.000	.000
KC			1.000	−.344**	−.157	.146	.295**	.291**
				.000	.044	.067	.000	.000
MIS				1.000	.111	−.067	−.139	−.259**
					.156	.398	.077	.001
Religiosity					1.000	−.275**	−.309**	−.398**
						.000	.000	.000
Believe						1.000	.320**	.501**
							.000	.000
Conflict							1.000	.378**
								.000
Learn school								1.000

*$p < .05$; **$p < .01$.

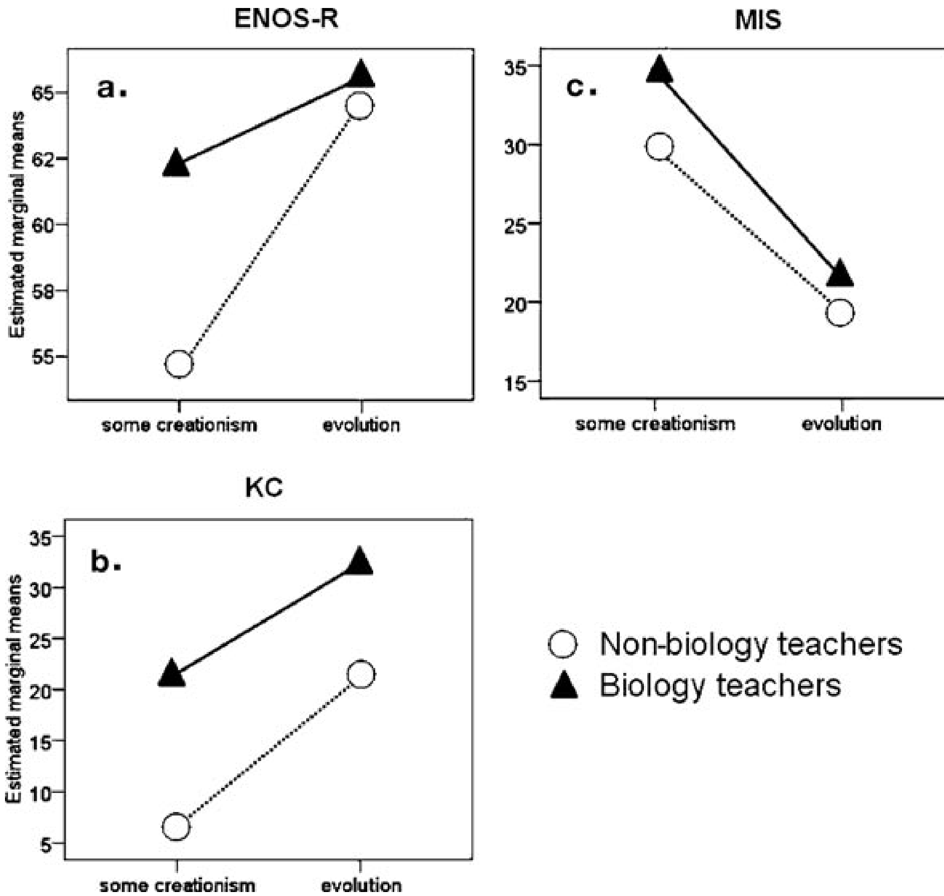

Figure 4. Two-way ANOVA results for (a) ENOS-R (evolutionary knowledge in relation to the nature of science, (b) KC (key concepts of natural selection), and (c) MIS (misconceptions of natural selection). Note that these analyses explore interaction effects among knowledge variables, belief stances (creationism and evolution), and certification area (biology vs. non-biology). Note that for panel C the greater misconception measures for biology teachers are likely a product of the much more detailed responses of these teachers to the open response items relative to non-biology teachers.

approximately 10% of the variation between variables in both cases. Greater misconception magnitudes (MIS) were significantly associated with teachers' preferences for including some creationism in school (learn school), although again this association was weak ($r = -.26$) (Table 2).

We used two-way ANOVAs to explore possible interaction effects among certification area (biology vs. non-biology) belief preference (evolution vs. "creationism") and knowledge scores (i.e., ENOS-R, KC, and MIS; Figure 4). Our data failed to satisfy the statistical prerequisites of a single MANOVA, and we therefore performed three separate ANOVAS—one each for ENOS-R, KC, and MIS. For ENOS-R, we found a significant main effect for *Certbio*, with greater mean scores for biology teachers ($F[1, 148] = 13.51$, $p < .01$, $r = .084$), as well as a similar significant main effect for learn school ($F[1, 148] = 32.07$, $p < .01$, $r = .178$). We also found a significant interaction effect between *Certbio* and learn school for ENOS-R ($F[1, 148] = 8.64$, $p < .01$, $r = .055$). For KC, we found a significant main effect for *Certbio* ($F[1, 159] = 19.91$, $p < .01$, $r = .111$), indicating greater scores for biology teachers, as well as a significant effect for learn school ($F[1, 159] = 18.78$, $p < .01$,

$r = .106$), indicating greater mean scores for teachers who want evolution alone to be taught in school. We did not, however, find a significant interaction effect between *Certbio* and learn school on KC scores ($F[1, 159] = 0.432$, $p > .05$, $r = .003$). Our final ANOVA explored the interaction effects of MIS. Although we found no significant main effect of *Certbio* ($F[1, 159] = 0.743$, $p > .05$, $r = .005$), we did find a significant main effect of learn school, with teachers who preferred the teaching of creationism demonstrating greater mean MIS scores relative to teachers who preferred that students be taught evolution alone ($F[1, 159] = 8.39$, $p < .01$, $r = .05$). There was, however, no significant interaction effect between *Certbio* and learn school on MIS scores ($F[1, 159] = 0.113$, $p > .05$, $r = .001$).

Although cumbersome, our multiple ANOVAs did reveal in some cases significant interaction effects among knowledge variables, certification area (i.e., biology vs. non-biology), and belief preferences (creationism vs. evolution) (Figure 4). In addition, the analyses demonstrated that biology teachers have significantly greater ENOS-R and KC scores relative to non-biology teachers, and that the two groups did *not* differ in their misconception magnitudes (Figure 4). Finally, the learning preferences of teachers (i.e., whether they preferred children to learn some creationism, or evolution alone, in school) were associated with significant differences in knowledge of natural selection (as measured by *key concepts*) and MIS. It is important to note that in nearly all cases the effect sizes were quite small, indicating that although significant differences were found, they were weak. In summary, the ANOVAs provided information about the associations among knowledge variables (KC, ENOS-R, and MIS) and teachers' preferences for the teaching of evolution in schools (learn school). The most important finding was that learn school was associated with differences in both teacher knowledge and misconceptions.

DISCUSSION

Despite more than 70 years of study concerning the evolutionary beliefs of college students (Dudycha, 1934) and nearly 40 studies on science teachers from 26 different states, much less research has focused on the association of academic preparation in biology on such beliefs. By studying precertified biology teachers with undergraduate degrees in the life sciences and precertified non-biology teachers from the same teacher preparation programs, we were able to test three hypotheses about knowledge and belief in regard to evolution: (1) biology teachers harbor greater funds of knowledge and possess fewer misconceptions of evolution and the nature of science than comparable samples of non-biology teachers, (2) biology teachers display greater magnitudes of acceptance of evolution and preference that students be taught evolution alone in school than non-biology teachers, and (3) knowledge of evolution and the nature of science is associated with the acceptance of evolution.

Overall, the teachers in our sample from New York City display comparable magnitudes of creationist preferences as science teachers nationwide. Like their colleagues in Kansas and Indiana (Aldrich, 1991; Rutledge, 1996; Troost, 1966), approximately half of the science (as well as nonscience) teachers in our New York City sample advocated for the teaching of some "creationist" perspectives in school and would personally prefer that children believe some "creationism" (recall that "creationism" was defined as encompassing creationism, creation "science," and/or intelligent design). Although we did find that biology teachers harbored greater funds of knowledge of evolution and the nature of science than non-biology teachers, as measured using two different variables (ENOS-R and KC), the two groups did *not* differ in their magnitudes—or types—of MIS.

Our second hypothesis—that biology teachers display greater magnitudes of acceptance of evolution and preferences for students to be taught evolution in school than non-biology teachers—was rejected. Indeed, biology and non-biology teachers displayed comparable perspectives on creationism; nearly half of the teachers in both groups preferred that creationism be included with evolution in the classroom (45.0% vs. 45.6%, respectively). Although our response items were not identical to previous studies, prior work suggests that about 50% of college students accept evolution (Bishop & Anderson, 1990; Fuerst, 1984; Grose & Simpson, 1982; Lord & Marino, 1993). For those enrolling in evolution courses, typically a highly selective group, Ingram and Nelson (2006) found that greater percentages of undergraduates accepted evolution than those documented in our study both precourse (61%–67%) and postcourse (70%–77%). Of the teachers in our sample who completed an evolution course, learn school scores were 58.3%. Thus, despite slightly different measures, the teachers' belief preferences in our sample do not appear to differ appreciably from college students nationwide, but they are lower than those in Ingram and Nelson's (2006) sample.

Our final hypothesis—teacher knowledge of evolution and the nature of science are associated with acceptance of evolution—is perhaps the most interesting and controversial. At a coarse level, this hypothesis was rejected. Indeed, our prior findings that (1) biology teacher knowledge of evolution and the nature of science is significantly greater than non-biology teacher knowledge, but (2) biology and non-biology teachers harbor comparable belief preferences (with nearly half advocating the teaching of creationism in school) tests this hypothesis, albeit in a crude manner. At a fine-grained level, however, we were not able to definitively reject this hypothesis: (1) the ANOVAs demonstrated a significant main effect for learn school and key concept and ENOS-R scores and (2) correlation coefficients indicated significant positive associations among learn school, KC, ENOS-R, as well as significant negative associations among learn school, MIS, and conflict. Thus, multiple analyses indicate that knowledge, misconceptions, and conflict are weakly associated with teachers' preferences for the teaching of evolution alone in schools. In summary, although it is surprising that nearly half of both biology and non-biology teachers prefer that "creationist" ideas be taught in school, this level of analysis does not reveal a complete picture of teacher understanding and belief.

Evolutionary Reasoning Patterns in New York City Teachers

In a brief sketch of evolutionary reasoning patterns in adults, Evans (2005) delineated four categories: (1) informed naturalistic reasoners, (2) novice naturalistic reasoners, (3) creationist reasoners, and (4) mixed reasoners. Although quite broad, this outline of reasoning patterns was used as a general framework for classifying teacher reasoning patterns in our sample. Evans (2005) concluded, based on studies of museum visitors, that most American adults may be classified as mixed reasoners, that is, they are characterized by a combination of reasoning strategies, such as *Novice* and creationist. To place our results within Evans' reasoning taxonomy, we used ENOS-R items, essay responses, KC and MIS measures, and self-reported attitude scores. Most distressingly, we found that remarkably few of the teachers in our sample—biology or otherwise—may be classified as informed naturalistic reasoners, that is, those who adopt exclusively Darwinian evolutionary explanations. Misconceptions about evolution and/or the nature of science are all too common, leaving us able to identify with certainty only a minority of biology teachers as *informed naturalistic reasoners*. Like Evans' (2005) sample of museum visitors, we find the majority of our science teachers to be mixed reasoners, with creationist reasoning patterns apparently present in approximately half of both biology and non-biology teachers in our sample.

Given that fostering scientific thinking, reasoning, and argumentation in children is a core goal of science education (Kuhn, 2005; National Research Council, 1996), a significant question that arises from these results is whether the biology teachers who participated in this study—and who have now emerged from their teacher education programs—are equipped to model and foster "informed naturalistic" reasoning in their classrooms. Indeed, how likely is it that the novice naturalistic reasoners, creationist reasoners, and mixed reasoners in our sample will be able to prepare children to become informed naturalistic reasoners? If, as Evans (2005) argues, most adults are mixed reasoners, then teachers who harbor similar reasoning patterns may be bolstering students' problematic ideational strategies rather than dismantling, rebuilding, and strengthening more robust scientific reasoning models. Clearly, given our findings, existing undergraduate programs and teacher education programs have largely failed to instill informed naturalistic reasoning strategies in both biology and non-biology teachers. This is a major failing that must begin to be explicitly assessed by scientists, science educators, and teacher education accreditation agencies (e.g., National Council for Accreditation of Teacher Education).

Religiosity and Conflict

Teachers and students have been shown to harbor negative perceptions of evolutionary theory (Brem et al., 2003; Fuerst, 1984). Personal conflicts between religious belief and science have been shown to cause greater stress for science teachers compared with those who do not experience conflict (Griffith & Brem, 2004). In addition, religiosity has been shown in some studies to be associated with acceptance of evolution (Dagher & BouJaoude, 1997; Sinclair et al., 1997). It is important to note that high religiosity need not be associated with conflict (Collins, 2007; Gould, 2002; Miller, 2000). Many of the teachers in our study self-report high religiosities but no conflict between science and religion (Figure 3). Although 18% of our sample did self-report being conflicted about the relationship between science and religion, this group was composed of more than twice as many nonscience teachers as science teachers. We did find, however, that high religiosity was associated with conflict in some teachers. Twice as many teachers of high religiosities were conflicted about the relationship between science and religion than those of low religiosities (12.3% vs. 5.6%, respectively). In addition, teacher conflict was found to be significantly associated with many variables—ENOS-R, key concepts, learn school, and believe. Thus, conflict is more strongly associated with teachers' knowledge and belief differences than religiosity. Given the availability of excellent resources for dissipating such conflict (Collins, 2007; Gould, 2002; Miller, 2000), it is likely that this variable may be mitigated via classroom instruction. Indeed, Nehm and Schonfeld (2007) found that conflict did decrease significantly as a consequence of explicit discussions of science and religion models. Finally, our study demonstrates that religiosity is not a segregator of science teaching specialties; many biology teachers' self-reported religiosities are not appreciably different from those of non-science teachers.

Knowledge of and Belief in Evolution

As Southerland and Sinatra (2003, p. 321) point out, the consensus view—that knowledge and belief are not closely linked cognitive constructs "... fails to receive a great deal of commonplace or intuitive acceptance." We concur and wonder why the burgeoning evolution education literatures—from large-scale survey research to small-scale qualitative studies—rarely contemplate the meaning of these results for policy or practice. In the only long-term (14-week) intervention study exploring knowledge and belief change in relation to evolution in a large sample ($n = 44$) of biology teachers, Nehm and Schonfeld (2007) demonstrated statistically significant gains in science teacher knowledge but nominal changes in teacher belief preferences, empirically corroborating the consensus view from the literature. Likewise, although Ingram and Nelson (2006) found that students' attitudes were positively related to final evolution course grades, the effect of attitude on achievement was quite small. Ingram and Nelson (2006) documented only a 9% increase in students' acceptance of evolution after completion of a semester-long evolution course. McKeachie, Lin, and Strayer (2002) found mixed results in their study; a disproportionately large percentage of students who initially reported "rejecting" evolution were found to have dropped the course or failed to respond to the postcourse questionnaire. In contrast, students who reported "accepting" evolution were found to have earned on average almost one full letter grade more than students who reported "accepting" creation. Thus, McKeachie et al.'s (2002) study is somewhat anomalous, in that it reports that beliefs or attitudes are linked to knowledge gain (albeit in a marginally self-selected sample).

The static data set used in the present study generally supports the quasi-experimental findings of Nehm and Schonfeld (2007), although statistically significant (but weak) associations between knowledge and teaching preferences were also uncovered. This weak association between knowledge of and belief in (or acceptance of) evolution, like that found in the present study, has been documented in several other investigations. Sinatra et al. (2003), for example, found little relation between knowledge of animal and human evolution and its acceptance, but did find a strong relation between these constructs in the context of knowledge and belief of photosynthesis. Deniz et al. (2008) studied a sample of Turkish science teachers ($n = 132$) to explore, among other issues, the intersection of evolutionary knowledge and belief. In contrast to the results reviewed above, their study concluded that "We found a significant correlation between participants' knowledge of evolution and their acceptance of evolution. . . . This indicates that participants who have more knowledge about evolution are more likely to accept the evolutionary theory" (Deniz et al., 2008, p. 13). It is important to note that "knowledge" accounted for less than 4% of the variance in "acceptance" in their sample. Thus, 96% of the variance in "acceptance" was *not* apparently explained by "knowledge." In contrast to Deniz, Donnelly, and Yilmaz's interpretation of their own analysis, we find their result to be in greater alignment with the conclusion that knowledge and belief have a tenuous relationship with regard to evolution. Several other studies have also documented the disarticulation between knowledge and belief, although many of these samples were not of science teachers and may be inappropriate comparison groups (Bishop & Anderson, 1990; Brem et al., 2003; Demastes et al., 1995).

In summary, the preponderance of findings on knowledge gain and its association with attitude and belief change both within and outside of evolutionary biology appear to be consistent with our finding that knowledge is weakly associated with beliefs toward the teaching of evolution in schools. Although some aspects of knowledge are indeed associated with teaching preferences, these associations tend to explain about 9% of the variance. Like the findings of Deniz et al. (2008), factors unrelated to funds of science knowledge explained a greater share of the variance in belief/acceptance. Religiosity, for example, was the most strongly associated variable with teaching preference in our study ($r^2 = 16\%$). Given that knowledge—and academic preparation in biology—explains much less than we might expect with regard to teachers' preferences for the teaching of evolution in schools, should knowledge gain alone be the focus of biology teacher preparation programs (Nehm & Schonfeld, 2007)?

Instructional Goals: Knowledge *and* Belief?

Although it is well recognized that knowledge and belief underlie many fundamental issues in science education (Jones & Carter, 2007; Southerland et al., 2001), there is little agreement about whether knowledge *and* belief change are legitimate goals of evolution education. A burgeoning literature about knowledge and belief has thus far focused on the theoretical, philosophical, and epistemological meanings of these concepts and the justifications for advocating them as learning goals (e.g., Alters, 1997; Chinn & Samarapungavan, 2001; Coburn, 1994; Cooper, 2001; Davson-Galle, 2004; Sinatra et al., 2003; Southerland & Sinatra, 2003; Southerland et al., 2001). This theoretical conversation has yet to be folded into discussions of—or designs for—practical classroom interventions in teacher education programs. This critical break between theory and practice could explain, in part, why teacher education programs are, at least in some cases, successful at increasing knowledge but unsuccessful at altering beliefs (whether or not belief change was an explicit goal; e.g., Nehm & Schonfeld, 2007; see also Jones & Carter, 2007).

Perhaps the most significant downstream effect of the weak association between knowledge and belief regarding evolution is that beliefs may impart a greater contribution to teachers' instructional task choice, curricular emphasis, and learning goals than knowledge (Donnelly & Boone, 2006; Jones & Carter, 2007). Indeed, Simmons et al. (1999) demonstrated that while beginning teachers in some cases *understood* a "student centered" approach to instruction, their beliefs and actions were often disarticulated from such knowledge (see also reviews by Jones & Carter, 2007). Thus, a critical question facing science teacher educators is how teacher preparation programs can facilitate coordinated conceptual articulation among teacher knowledge, beliefs, and behavior with regard to the teaching of evolution (and other topics).

Study Limitations

Static–correlational research designs in science education have many limitations, the most significant of which is an inability to establish causal relationships among variables. Conflict, religiosity, certification area, knowledge, beliefs, and misconceptions likely interact in complex causal networks that cannot be readily untangled through the use of atomized hypothesis tests (as we attempted). In addition, the instruments used to measure teacher knowledge of evolution and the nature of science in this study are admittedly crude, although this weakness applies to nearly every study within the field of evolution education (Nehm & Schonfeld, 2008). Likewise, test fatigue and consequent reliability threats are serious issues in quantitative evolution education studies; test batteries are becoming increasingly time-intensive and unwieldy (e.g., see Deniz et al., 2008; Southerland & Sinatra, 2003). Work is needed to fine-tune our instruments so that we may extract more high-yield data with less participant time investment. It is also possible that teacher self-reports of religiosity may be influenced by the religion one subscribes to; for example, self-reports that "religion is a very important part of my life" may encompass strict or literal adoption of religious tenants in some religions but not in others. Thus, more fine-grained items pertaining to religiosity would undoubtedly enrich our understanding of the significant associations of this variable that we documented. Moreover, taxonomies of belief/acceptance/advocacy necessarily compartmentalize amorphous constructs into neatly circumscribed boxes; qualitative data may reveal richer and more nuanced scales of analysis. Likewise, qualitative studies that seek to expose the ideational networks that generate teachers' beliefs and dispositions would elucidate the thinking behind closed-response choices, such as why so many biology teachers prefer that students personally believe creationism or why some teachers of high religiosities report no conflict with a scientific worldview. Overall, despite limitations, our descriptive/correlation study design has nevertheless revealed many useful findings, among them the observation that biology and non-biology teachers from New York City, arguably one of the most liberal cities in America, harbor comparable antievolutionary worldviews as teachers from other regions of the nation, and that knowledge and belief appear to be weakly associated constructs in this sample.

CONCLUSIONS

In summary, our study—believed to be the first of New York City biology and non-biology teachers' knowledge and beliefs about evolution—suggests that no region of the nation is immune from antievolutionary beliefs among science teachers. Combined with studies from 26 other states, our results paint a disorienting portrait of biology teachers in the United States: despite years of college-level science preparation, evolution coursework, and the personal choice to pursue such studies, large numbers—nearly half—of biology teachers prefer that students be taught some creationism in schools *and* that students personally believe creationism. Remarkably, these findings for biology teachers barely differ from a comparable sample with little or no undergraduate biology coursework. This striking discordance between science knowledge generated during years of academic preparation and personal belief is conceptually counterintuitive but empirically robust. Much more work is clearly needed to corroborate our conclusions on a broader scale, and theoretical work is urgently needed to conceptualize the implications of such discordance for the practice of science teacher education. Overall, our results question whether current academic programs in the biological sciences significantly impact teachers' evolutionary knowledge or beliefs. Longitudinal studies of evolutionary knowledge, belief, and reasoning patterns through undergraduate biology programs hold great promise in elucidating the causes of stability and change in biology teachers' evolutionary epistemologies (Floden & Meniketti, 2005).

APPENDIX: ENOS-R ITEMS

1. As evolution cannot be observed, it is outside the realm of science.
2. After scientists determine that theories are well supported, they refer to theories as facts.
3. Evolution cannot be proven.
4. In scientific terms, both gravity and evolution are theories.
5. Chance cannot be a key factor in the origin of complex organisms.
6. The fossil record documents transitional intermediates (missing links) between ancestors and descendants of many species.
7. Mutations are harmful and therefore cannot give rise to new characteristics.
8. If evolution were true, "living fossils" like the horseshoe crab would not have stayed the same for millions of years.
9. Radiometric dating of rocks indicates that the Earth is <u>billions</u> of years old.
10. Evolution is weaker than many other scientific concepts because it is only a theory.
11. Fossil species have been found that are intermediate between humans and apes.
12. The survival of early humans was difficult because of predatory (carnivorous) dinosaurs.
13. No one can know about events before there were people to observe and record them. Therefore, past evolutionary events can never really be known.
14. Creationism is <u>not</u> science, because it is not testable by using the methods of science.
15. Many biologists and paleontologists reject evolution.
16. The organisms that cause malaria, gonorrhea, and tuberculosis have become resistant to antibiotics. The biological cause of this resistance is evolution.
17. A hypothesis must be capable of being tested (verified or falsified) in order for it to be in the realm of science.

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