The identification, assessment, and amelioration of barriers to America's acceptance of evolutionary theory

Richard F. Firenze

Abstract

The scientific community is in near universal agreement as to the importance of an understanding of evolutionary principles as the unifying theme for the appropriation of the origin, history, and diversity of life on our planet. Yet despite this agreement evidence from myriad sources indicate that most Americans reject this grand-unifying theory of the life sciences. Although the reasons for this rejection are both numerous and complex they are undoubtedly related to American pedagogical failures and the persistence of alternative views based on faith. It appears misconceptions of evolutionary theory can be divided into two major categories: 1) epistemological misconceptions--those dealing with the nature of scientific inquiry; and 2) content misconceptions--those dealing with the process and mechanisms of evolution itself. An understanding of the Conceptual Change Model, indicating that in order for misconceptions to be abandoned they must first be deemed unsatisfactory to the learner, while new conceptions must be intelligible, plausible, and fruitful, may be useful in our efforts to promote a better acceptance of evolutionary theory. We must further recognize that "concepts" and "beliefs" have both force and scope and that science and religion are worldviews steeped in the viscous broth of these two elements.

Introduction

Publications by the National Research Council of the National Academy of Science (National Science Standards 1996B) and the American Association for the Advancement of Science (Benchmarks for Scientific Literacy 1993) have placed the highest priority on teaching science as both a mode of inquiry and with central overarching unifying themes. AAAS (1993) refers to these themes as "ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design" (p. 261). Both of these documents, as well as the vast majority of scientists and science educators, seem in virtual agreement as to the importance of an understanding of evolutionary principles as the unifying theme for the appropriation of the origin, history, and diversity of life on earth as a scientific concept. At least thirty-two scientific organizations have gone so far as to publish specific statements advocating the use of evolutionary theory in science classrooms as a "mega theme" upon which an understanding of the life sciences must hang (Matsumara 1995). The AAAS Benchmarks for Scientific Literacy (1993) states that "the educational goal should be for all children is to understand the concept of evolution ... the evidence and arguments that support it, and its importance to biology" (p. 254), while the National Research Council's National Science Standards (1996) state that "biological evolution cannot be eliminated from the life science standards" (p. 112). The Society of the Study of Evolution has joined seven other scientific organizations in issuing a white paper on the importance of teaching evolution (D'Avanzo & McNeal 1996). Recently the Royal Society of London (2006) issued a statement that "evolution is recognized as the best explanation for the development of life on Earth" and it is "rightly taught as an essential part of biology and science courses in schools, colleges, and universities across the world." No fewer than forty three organizations of science educators agree with these statements as illustrated by the National Science Teachers Association, National Association of Biology Teachers, and the Society for College Science Teachers repeatedly publishing articles in their respective journals calling for evolution and the nature of scientific inquiry to be the core of life science education. The NABT's position states that "Teaching biology in an effective and scientifically-honest manner requires classroom discussions and laboratory experiences on evolution (National Association of Biology Teachers 1996, p. 98, emphasis mine). The NSTA's position statement on The Teaching of Evolution states that the organization "supports the position that evolution is a major unifying concept of science and should be included as part of K-college science frameworks and curricula" (Journal of College Science Teaching

1997, p. 6). At least thirteen religious organizations have produced documents supporting the dialectic nature of the creation/evolution controversy. Perhaps this view is articulated best by the Right Rev. Bennett J. Sims, Episcopal Bishop of Atlanta, when he says, "If the world is not God's, the most eloquent or belligerent arguments will not make it so. If it is God's world ... then faith has no fear of anything the world itself reveals to the searching eye of science" (Matsumara 1995 p. 91). Over the past few years scores of texts have been published, many by the world's most eminent scientists, extolling the importance of evolutionary theory in science education. The following series of quotes give a flavor of scientists' and educators' views on this topic:

> The modern concept of evolution provides a unifying principle for understanding the history of life on earth, relationships among living things, and the dependence of life on the physical environment. (Rutherford & Ahlgreen 1990, p. 63)

> Evolution is the unifying concept, the commonality that ties all earth's life together. (Keown 1988, p. 40)

> For the science of biology, the theory of evolution provides a unifying framework within which many diverse facts are integrated and explained. (Bishop & Anderson 1994, p. 415)

> Evolution is .. [for biology] .. as the atomic theory is for chemistry. Biology no more makes sense without the unifying conceptual scheme of evolution than the elements could be ordered without an understanding of atomic theory. (Mayer, 1984, p. 423)

Considering these positions it would appear that educators and scientists alike support the now famous statements of Dobzhansky (1973), that "nothing in biology makes sense except in the light of evolution" (p. 125), and Medawar (1977) that, "for a biologist, the alternative to thinking in evolutionary terms is not to think at all" (p 23). In fact, the argument for teaching evolution is antecedent to both Dobzhansky and Medawar by some one-hundred years. Famed German biologist Ernst Haeckel argued for the teaching of evolution in his classic, but often overlooked, text Freedom in Science Teaching published in 1879 and Thomas Huxley's "On the Study of Biology," a public speech given in 1876, advocates the same. More recently Tamir (1993) argues that evolution should not just be taught in all science classes, but should be taught early and often. He reasons that evolutionary principles: (a) allow students to make sense of what they learn by interpreting seemingly disparate material within the context of a unifying principle, and (b) serve as excellent advanced organizers for the study of biology. As Storey (1997) has stated in his highly appropriate sports metaphor, it's not just time to bring Darwin into the starting lineup, its time to make him our opening day pitcher.

Despite the logic of the compelling cry from our scientific community to infuse evolutionary principles and the nature of science into the curricula, evidence indicates that most students leave our science classrooms, at all levels, (elementary through university) with great and grave misconceptions of these vital concepts (Alters & Alters (2005); Bishop & Anderson 1990; Bizzo 1994; Brumby 1984; Clough & Wood-Robinson 1985; Demastes, Trowbridge, & Cummins 1992; Jungwrith 1977; Kargbo, Hobbs &

Erickson 1980; and Keown 1988). A number of other studies have also shown a reluctant and confused American public when it comes to a true understanding of evolutionary theory (Bergman 1979; Christensen & Cannon 1978; Cole 1988; Fuerst 1984; Harold & Eve 1987; Scott 2005; Stewart 1992; and Zimmerman 1986, 1987, 1990, 1991). In fact, a recent Harris Poll (2005) shows that 54% of U.S. adults do not think human beings developed from earlier species and 64% felt that human beings were created directly by God. Only 22% indicated that human beings evolved from earlier species. The Pew Forum (2005) shows 42% of Americans indicating they accept the statement that "Life on Earth Has Existed in its present form since the beginning of time." The National Science Foundation's "Science and Engineering Indicators," (2004) found only 44% of the respondents agreeing with the statement "Human beings, as we know them, developed from earlier species of animals." Recent legal developments in the U.S. regarding the teaching of evolution in public schools caught popular media attention resulting in a Gallup Poll (2005) showing that three-quarters of Americans have thought at least a "moderate amount about the origins of human beings" while two-thirds report that it "matters which theory of origin (creation/evolution) is correct." Zimmerman's (1991) research on school board presidents in Ohio indicates that: 1) the majority felt that creationism should be taught in schools, 2)the school boards, not the individual instructor, should make this decision, and 3)the science curriculum should be determined as much by public opinion as by the scientific community. In fact all fifty states have had proposals to either reduce or remove evolution from the curriculum, or teach creationism and/or teach intelligent design in public schools (Holden 2004). Perhaps the title of a recent New York Times editorial summarizes it best, "Evolution Takes a Back Seat in U. S. Classes" (Dean 2005).

It seems as though as scientists and science educators we are compelled to ask that simple question put forth by Eugenie Scott, Director of The National Center for Science Education, "What makes well-meaning people fight so hard to keep children from learning a basic scientific principle?" (Scott 1996, p. 20).

The reasons for this rejection of evolution are both numerous and complex ranging from the overtly obvious to the sublimely subtle. Fig.1 illustrates some synergistic areas that need to be addressed if we hope to overcome these barriers and accommodate a public acceptance of evolutionary theory.

[FIGURE 1 OMITTED]

Although each area in Fig. 1 is vitally important to address, this paper will focus mainly on the pedagogical sphere since it is this educator's belief that America's pedagogical failures and the related persistence of more acceptable alternative views based on faith are not only the warp and woof of our reluctance to accepting evolutionary theory but are also the most accessible to change. Most would agree that, outside of the mass media, the educational system is the most expeditious method to reach the American public. It is the responsibility of our scientific community to insure that our educational system, at all levels, produces a scientifically literate public. Only then will we have a more accommodating citizenry who may look at this gloriously diverse world of life though evolutionary eyes.

Personal observations, as well as data collected from thirty-six years of teaching biology at the colligate level, simply reinforce the view that misconceptions concerning evolutionary theory run amuck in our educational systems. These misconceptions can be divided into two major categories:

1. Epistemological Misconceptions--those dealing with the nature of science.

a. Evolution violates the second law of thermodynamics.

b. Evolution is "only" a theory.

c. Since biologists can not see species evolve, evolution is not truly science.

d. Since evolution is not subject to "controlled" experiments, it is not truly a science.

e. Prominent biologists have made statements disputing evolution.

f. Evolution has never been proven correct.

g. If you believe in evolution you must be an atheist/agnostic.

2. Content Misconceptions--those dealing with the process of evolution.

a. Humans evolved from monkeys.

b. Mutations are always harmful.

c. Life is too complex to have come about by random chance.

d. If [mammals] evolved from [reptiles], then why are there still [reptiles]?

e. Through evolution, organisms get what they need to survive and reproduce.

f. There are no transitional fossils.

g. The [eye] is too complex a structure to have evolved in stages.

h. Some organisms have not changed in millions of years, thus disproving evolution.

i. Organisms progress from "lower" forms to"higher" forms.

Experience compels me to agree with Volpe's (1984) assessment that "students enter college with vague and naive notions about evolution" (p. 435), Smith's (1994) conclusions that "students bring to the classroom not only misconceptions about the science involved, but also substantial historical, religious, and political baggage that can limit their understanding" (p. 591), and Ayala's critique of evolution education, that "we are doing a miserable job in our schools and in educating the public at large" (quoted in Schmidt 1996, p. 422). Perhaps this is not surprising since Tamir (1993) notes that "there is relatively little research done on the teaching and learning of evolution and [that] the little that exists has not been carried out in the United States" (p. 83), and Good (1992) states that "Considering the central role evolution plays in the life sciences, it is curious that relatively little research has been done on evolution education.... Understanding how students grapple with the existence and mechanisms of the evolution of life should be a goal as central to science (biology) education as Darwinian theory is to biology itself" (p. 1019). In fact, so little research has been done we do not know if this "baggage" discussed by Smith (1994) needs to be jettisoned or simply modified. However, it seems obvious that all facets of this problem must be taken into account if we hope to develop successful instructional planning in the most central and controversial theme in the life sciences.

This view is reinforced by a special issue of the Journal of Research in Science Teaching published in May of 1994. This issue was dedicated to research involved in the teaching of evolution. In the lead article, entitled "Evolution: Biological Education's Under-Researched Unifying Theme," the authors state that "despite the centrality of evolution to biology, relatively little research on evolution education has been reported" (Cummins & Demastes 1994, p. 445). The authors lament that "much work still needs to

be done both in science education research and in curriculum development to produce materials and methods that effectively convey to students the complexity and elegance of evolutionary theory" (p. 446). It is my assertion that very little meaningful curricula can be developed, nor scant progress made, until the perceived barriers to the incorporation of evolutionary theory and the nature of scientific inquiry, as central themes in the classroom, have been identified, assessed, and at least partially ameliorated.

In an effort to incorporate the near universal suggestion of teaching biology thematically while using evolution as the central theme, five two-week summer institutes entitled EVOLUTION AND THE NATURE OF SCIENTIFIC INQUIRY: Using Evolution as a Central Theme in the Life Sciences were developed and offered to a total of sixty 7th and 10th grade life science teachers over five consecutive summers at Binghamton University. The institute was supported by a grant from the Howard Hughes Medical Institute and taught by Dr. Thomas O'Brien, K-12 Science Educator, and myself. Pre-institute questionnaires and interviews attempted to determine the barriers to the infusion of an evolutionary theme in the classroom and much of the institute was designed to overcome these perceived barriers.

This research also attempted to follow several of the participants for an academic year with continued participant feedback and networking. Using a combination of both quantitative and qualitative research methodologies it was hoped the researchers could gain a better understanding of: 1) What are the perceived barriers to the incorporation of evolutionary theory as a central theme? 2) Can these barriers be partially and/or completely overcome as a result of participation? 3) Will additional classroom time be spent on the topic of evolution? 4) How influential will the institute be in making determinations of classroom content? 5) Will the perceived barriers actually be encountered by the participants when they infuse evolution into their classes?

It was concluded that participants generally reported a reduction in their perception of barriers to the incorporation of evolutionary theory, both on post-institute surveys and post-delay (final) surveys at the end of the academic year. Seven of ten "perceived barrier categories" (see table 1) showed a statistically significant decrease when subjected to a paired t-Test analysis *. "Lack of time," "personal inertia," and the "controversial nature of the topic" were identified as the most persistent barriers.

One of the general conclusions reached from this study was that the misconceptions our students have in regard to evolutionary theory and the process of science are shared not only by the American public but also by their teachers (Firenze 1997).

Most participants reported feeling more comfortable and confident dealing with the topic of evolution and reported spending more classroom time on evolution throughout the academic year.

Seven recommendations emerged from this research which may well help ameliorate the perceived and actual barriers encountered by today's educators and thus ameliorate the barriers perceived by the American public.

Recommendations

1. It would appear that a course on the philosophy of science and/or the nature of scientific inquiry should be incorporated into all curricula offering a degree in science education. All pre-service science teachers should be required to take a course dedicated to the central themes of the philosophy/history/nature of science and in-service programs should be offered frequently in this area. I am certainly not alone in this request (Alters & Alters 2005; Clough 1989; Duschl 1990; Duschl & Hamilton 1992; Johnson & Peebles 1987; Matthews 1989; Monk & Osborn 1997; Nunan 1989; Pigliucci 2002; Schmittau 1991; and Summers 1982).

Dovetailing with this recommendation is the concept that all science courses, at both the undergraduate and graduate level, should model, not only a thematic approach to their discipline, but should be taught with an emphasis placed on science as a way of knowing. The didactic, almost biblical, nature of the treatment of science in most college courses must cease. Courses on both pedagogy and discipline must work together if we are ever to hope for success.

Robert Marcus, Provost of Rollins College, argues that we are not letting our students think or act scientifically. He posits that, while in the classroom, we are serving our students "full meals" when we should be inviting them into our kitchens to sort through the "ingredients of science" (Volpe, 1983). However, sorting through these ingredients without the basic recipe of evolution, and a true understanding of the nature of science, can only result in an unpalatable culinary concoction.

Studies by Brickhouse (1989) and Lederman & Zeider (1987) have shown the overriding influence that a teacher's views on the nature of science can have on what their pupils finally accept as representative of the scientific method and scientific knowledge. This appears to hold true even if the teacher's views are not taught explicitly. As Solomon et al. (1996) states, "in the hands of the gifted teacher the pupils' experiments can become a procedure for the collecting of evidence to test predictions which were themselves based on modeling of established theory" (p. 506).

Research by Johnson & Peebles (1987) indicated that students were much more likely to be accepting of evolutionary principles as their understanding of the nature of science increased. Unfortunately this same research reported that most biology majors have a poor understanding of the scientific process. Considering the "other side of the desk," Scharmann & Harris (1992) reported that promoting a better understanding of the nature of science in teachers reduced their anxiety toward teaching evolution.

The data from our own study indicate that most of the participants confused the history of scientific inquiry with the biographic history of scientists. There is, in fact, a world of difference between discussing the "evolutionary" history of the development of scientific thought and the fact that Anton von Leevwenhook was a draperies maker in Delft.

Our study indicated that scientific methodology was confined to a strict Baconian logicoempiricist view; the view expressed by most textbooks and found on many state curricula and exams. Studies by several other researchers indicate that this view of the nature of science is pervasive throughout science education (Alters & Alters 2005, Abimbola 1983; Duschl 1990; Hodson 1988, Pugliucci 2002).

Eugenie Scott has stated that most "critics of science and evolution criticize from a serious lack of understanding of how science works" (quoted in Barbero 1994). Agreeing with Scott, Murray Gell-Mann (1994) feels that it is our general misunderstanding of the term "theory" that lies at the roots of our misconceptions. Rather than considering a theory a "coherent system of rules and principles, a more or less verified or established explanation accounting for known facts or phenomena [most people consider it] a speculation, a guess or conjecture" (p. 91).

A course of this nature is no guarantee that the call for the central themes of evolution or nature of science will be heeded, but it appeared that the participants in our study who truly recognized the importance of the nature of scientific inquiry were much more comfortable in dealing with the topic of evolution and much more likely to incorporate it. This seems to corroborate the work of Johnson & Peebles (1989) and Scharmann & Harris (1992). This would also agree with Stoflett's (1994) argument that many of our student misconceptions of the nature of science stem from the dominant, didactic paradigm of science teaching and learning, and the work of Dagher & BouJaoude (1997) which indicates that students are more likely to embrace evolutionary theory if they are allowed to openly discuss it and its relationship to their own personal view of the nature of science.

Research by Palmquist & Finely (1997) indicates the success of a pre-service science teaching program that uses the contemporary teaching strategies of conceptual change and cooperative learning to make positive changes in the participants' views of the nature of science even when little direct instruction on this topic is included. Their research shows a marked increase in pre-service teachers who indicated a "conversion" from a traditional view to a more contemporary view of science after participation in their program.

Monk & Osborn (1997) argue that in order for a history or philosophy of science course to be effective, and thus incorporated into the science classroom, it must offer the prospective teacher proof that it will indeed assist their students with the understanding of scientific principles and will be consistent with the main goals of the nascent teacher.

Teacher educators must realize that how we educate our teachers directly translates to how our teachers educate their students; and that there is a direct correlation between the perception of the nature of science and the nature of science teaching. However, teachers are not only educated in school, but also in the non-academic "real world." They develop their worldview of science from both. And perhaps the most influential is more than likely the one over which we have the least control.

2. Evolution needs to be addressed early in the educational system and addressed in a non-apologetic, non-controversial fashion (Firenze 1997; Firenze & O'Brien 2005; Howe 1996; Keown 1988; Pugliucci 2002, Settlage 1994, Smith 1994; and Tamir 1993). Along with this, the general public must be educated that evolution does not equal atheism. Research conducted by Edward Larson (1996) indicated, that despite almost a century of evolution under our belt, the belief in an actively communicating God who "communicates with humankind and to whom one may pray in expectation of receiving an answer" has remained remarkably stable throughout this century (Angier 1996, p. 1). Based on the original research of James Leuba conducted in 1914, Larson's work shows that a consistent 40% of the scientists polled believe in this very restrictive definition of the term God. Leuba had predicted that the number would greatly diminish as the century unfolded and people became more educated in, and reliant upon, the sciences. Leuba's original survey was used as fodder for William Jennings Bryan's arguments for the dangers of teaching evolution in public schools in the 1920's culminating in the infamous Scopes Trial of 1925. Sadly similar refrains are still being heard from those from those advocating the teaching of "intelligent design" culminating (hopefully) in the Dover School Board Trial of 2005 (Kitzmiller v. Dover).

It is easy to recognize not only from the data gathered in our study, but from the myriad studies before, that students (I would also add teachers) come to school, to a large extent, ready to accept or reject evolution and this acceptance or rejection begins prior to the formal educational process. Unfortunately this stance is largely based on religious beliefs and the perceived dichotomies. WE MUST START EARLY. As Alexander Pope has said, "Just as the Twig is bent, the Tree's inclin'd".

3. Not only must all undergraduate courses in the sciences be taught with a theme emphasizing the nature of science, but all courses in the biological sciences must be taught with an overt evolutionary theme. Biology, like all science, has for too long been taught as a "disembodied or arcane bank of facts" (Edwards 1997, p. 332). Instructors cannot assume that evolution is "just understood" as the central theme. It must be fully stated in an overt fashion and adhered to. Scott (1997 & 2005) has argued convincingly that much of the blame for our science teachers not teaching evolution must lie at the feet of the science professors who teach them. Before we can expect our teachers to offer courses with central themes, we must model such teaching in our own classes.

4. Related to and enhancing recommendation #3, all life science teachers should be required to take a

course in the principles and processes of evolution. It is difficult to imagine a life science teacher graduating from a reputable institute of higher education without a course in cellular and/or molecular biology. "After all," the argument goes, "how can we understand life if we don't understand the cellular basis to life?" As accurate as this inquiry may be, it can be rhetorically asked with equal assurance, "How can we understand life if we don't understand the process which gave rise to its origin and diversity?" To quote Dobzhansky (1973) again, "Nothing makes sense in biology except in the light of evolution" (p.173). But to teach evolution, to incorporate it as a central theme, you must first understand it. The majority of participants in our study stated they could not recall a single course, in either their undergraduate or graduate program of study, in which evolution was used as a central theme. Only four of the participants actually took a course on evolution and for all four it was an elective.

Shanker et al. (1993) report that of the five independent variables studied: academic background, years of teaching experience, size of school enrollment, teachers' understanding of evolution, and teachers' degree of religious conservatism; the teacher's understanding of evolution was most highly correlated with the dependent variable of time allocated to teaching evolution. Surely a required course in evolution should enhance understanding and thus help to alleviate any barrier this may cause.

The same researchers also found that only two other variables correlated with time spent on teaching evolution: years of teaching experience and size of school enrollment. Interestingly the data from our study indicate the opposite. The participants in our study that both professed the desire to spend more time on the topic of evolution and, in fact, reported doing so, were those with less experience; and there was no correlation between size of the school district and time spent on evolution. Shanker et al. (1993)report that teachers who had less academic preparation in the sciences had both a lack of understanding of the process of evolution and taught creationism more than their counterparts. Since the most important variables seem to be academic background and understanding of evolution, it appears that a course of this nature is needed if we are ever in hope of increasing both the quantity and quality of evolution education in our schools. Accordingly, we must also limit, if not ban outright, out-of-field science teaching.

Beardsley (1992) points out that any effort to improve science education is moot without skilled teachers. And skilled teachers are not in plentiful supply. Norman (1991) reports that 69% of science teachers in middle schools fall short of standards set by their own professional associations. In high school, the figures are no better with 71% of the biology teachers having substandard preparation. Although the Office of Science and Technology states that "students in colleges and universities are much more able to cope with less than superb teaching" (Tobias 1992, p. 88), they fail to recognize that it is here that we train our future elementary and secondary educators; it is here we either turn them on-or off-to science. Science students in college consistently complain about a constant focus on memorization, the rapid pace, and little relevancy in their introductory courses. As one student put it, "it was all scales and no music" (p.87). As science educators we must let the music ring loudly and harmony will only come when our subject is taught with central unifying themes. And, as emphasized repeatedly in this paper, the life sciences have the perfect theme upon which to let its subject stay in tune.

5. Life science textbooks need to be written with the overt themes of the nature of science and evolution permeating the entire text. To some extent these texts are available, but the themes need to be expanded and strengthened. A textbook analysis done in our research points out that, even when overtly stated in the text, it is likely that neither evolution nor the nature of science is truly used as a central theme throughout. We must recognize the fact that science and scientific knowledge are not a conglomeration of facts that are derived from books and therefore best suited for multiple choice tests and worksheets that require little, if any, critical thought process.

Glen (1990) found that many texts used the terms "arose," "arrived," "thrived," "progressed," "appeared,"

"became extinct," "made important advances," and "gave rise to," but refused to use, or used infrequently, the actual word evolution. Ancillaries such as lab exercises, projects, exams, etc. must not only contain these themes, but must do so in a way that promotes critical and creative thinking. The research of Germann et al. (1996) indicates that, although most lab manuals profess a desire to promote critical thinking skills in a scientific vein, an analysis indicated that few actually called upon the students to use their knowledge to pose questions, solve problems, investigate natural phenomena, or construct answers to generalizations.

6. Life science courses need to focus on depth not breadth. Time will forever be the enemy of life science teachers. As scientific knowledge increases exponentially surely this will only get worse since it is extremely common for most educators to measure their success on the quantity of material they cover. They are much more concerned with what and how much they cover rather than what and how much their students learn. There is a tacit, and incorrect assumption, of a direct correlation between these two variables. Due to the very nature of their profession most teachers do not consider, nor measure, long-term retention of conceptual information. Despite this we must convince our teachers and our curriculum developers that less can be more (unfortunately less often times becomes less) and central themes must replace rote memorization and vocabulary. Lectures and labs must become what Benjamin Barber (1992) calls "invitations to inquiry" (p. 81). This is far from a unique nor innovative call. John Dewey (1910) called for this almost a century ago when he said;

> I mean that science has been taught too much as an accumulation of ready-made material with which students are to become familiar, not enough as a method of thinking ... [and] when our schools truly become laboratories of knowledge-making, not mills fitted out with information hoppers, there will no longer be need to discuss the place of science in education (p. 192).

Many for our students resist looking at the big picture. They don't want to comprehend the concept, they want to pass the test. Many students, if not most, want to remain as passive learners. Who can blame them? After all, they are graded on the test and more than likely the test will not assess them on how well they understand the concept, but on how well they have memorized the terms. And of equal importance the teacher is "graded" on how well their students do on the tests. The answer seems painfully simple and straight-forward; construct the test following the guidelines for authentic assessment and thus test for conceptual understanding, not rote memorization (AAAS 1993; Alters & Alters 2005; Firenze 1998, 2005b; National Research Council 1990, 1996; Pigluicci 1992; Rosen 1989).

7. Perhaps the single most important concept that can be addressed to encourage the incorporation of evolutionary theory as a central theme in life science classes is to erase the false dichotomy that exists between science and religion; and in particular between religion and evolutionary theory. It belabors the obvious to state that this is neither an easy task nor one that hasn't been challenging humankind for centuries. It can be seen in the classic writings of Greek philosophers who debated secular skepticism and metaphysical idealism (Tarnas 1991), through the Renaissance battles fought between the church and the budding influence of nascent science; to the post-modern philosophers of today (Firenze 1997; Pigluicci 1992; Tarnas 1991; Thomson 2005). But the longevity of an argument need not indicate its permanence.

The dualistic perspectives described by Perry (1970), as seeing the world as either right or wrong and Dewey (1938) as mankinds' great desire to think in terms of extreme opposites, certainly play a role in determining this dichotomy. Gould (1997) has called this tendency to reduce our most complex issues to a simple choice between two diametrically opposed alternatives, both natural, an effort to promote order in a disorderly world, and "our worst mental habit" (p. 18). This dichotomous view has, indeed, created the "two cultures" feared by C.P. Snow (1959) and as such, science, for many, has become an alienating

world.

All too often evolution education can be crusading and confrontational. It is taught both dogmatically and dichotomously with religion. As Costa (1995) and Dennett (2005) point out, it seems that evolutionists equate a fundamentalist's belief in the origin, diversity, and history of life with close mindedness and ignorance, while many creationists equate the belief in evolution with atheism or agnosticism, and thus immorality. This absolutely needs to cease. These worldviews are not necessarily incompatible as has previously been discussed in several parts of this paper. Our preservice and in-service teachers must be fully cognizant that the "belief" in evolution does not force one to take a Hobbesian view that will lead to "no arts; no letters; no society; and which is worst of all, continual fear and danger of violent death; and the life of man, solitary, poor, nasty, brutish, and short". Such a view was eschewed by Darwin (1859) when he ended his opus with;

> There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved (p. 460).

These forms of life, the subject of our discipline, are indeed most beautiful and wonderful, and it is imperative that life science teachers convey this message to their students in such a fashion that is consistent with both the nature of science and the worldviews of themselves and their students. What a shame that the most famous of all quotes on the topic of evolution, one in fact used several times in this paper; Dobzhansky's (1973) "nothing makes sense" quote, is not overshadowed by a line found but two pages away in his original article; "It is wrong to hold creation and evolution as mutually exclusive alternatives" (p. 129).

Paul Quinnett (1996) states that some call the journey of life a miracle; others call it luck. The fact is, it's both, and it should be taught that way.

Tamir (1993) tells us that the "teaching of Evolution poses two dilemmas, one concerned with pedagogy and the other with faith" (p. 75). In a similar vein Cobern (1996) implores us to look at a "concept" or "belief" as having the qualities of both force and scope. He states that a "concept or belief has force if it is central in an individual's thinking rather than marginal. A concept or belief has scope if it has relevance for the individual over a wide range of contexts" (p. 580). He continues to argue that, although conceptual change is a relatively simple idea, science education is headed down the wrong path if it feels that we can change students' conceptions by trying to convince them that science is more intelligible, plausible, and fruitful than other worldviews they may hold. This can only lead to what he calls "cognitive apartheid" (p. 591), in essence, a false separation of what they learn in school and what they know from the "real world." Instead we should be trying to weave science into a general milieu of all disciplines. In Cobern's view we should be looking for the development of a scientifically compatible worldview not necessarily a scientific worldview. However there may also be more than a modicum of danger in heeding this advice. Science is not merely a cultural construct, and any worldview that ignores or minimizes the steadily improving predictions of twentieth-century science is surely less than completely sound.

There can be little doubt that science and religion are worldviews steeped in a viscous broth of both force and scope. If these two concepts, or belief systems, are unnecessarily dichotomized then barriers will undoubtedly be formed that will preclude the formation of any possible concordance.

Jackson et al. (1995) approaches this problem by dividing the teaching of evolution into four categories:

* The crusading spirit-expurgating religion for a higher principle of science.

* Use of the creation-evolution controversy to critically discuss the issue and its relationship to the nature of science.

* Allowing less anxiety to arise in the classroom by allowing alternative views to arise in an informal less structured classroom.

* De-emphasizing the importance of the scientific worldview in a pluralistic society.

Neither the first nor the last of these "techniques" has any place in a first-rate science classroom. The authors state that we must use the students' hearts to engage their minds. I completely agree, but I would only add that we must use their minds to inform their hearts.

Nelson (1986) indirectly addresses Jackson's third approach in his research which indicates that for those teachers who fear "not being an expert on evolution" a studentcentered classroom successfully frees the teacher from this role. That being the case, and recognizing the considerable benefits in this method of instruction, I still cannot help but wonder; if this is the only time this educational strategy is used in the classroom what messages about the science of evolution does this send to the student?

Phelen (1993) describes four paths of "migration" of students into a scientific worldview and thus I would conclude a worldview more conducive to the acceptance of evolutionary theory:

* Congruent Worlds/Transition Smooth

* Different Worlds/Transition Managed

* Difficult Worlds/Transition Hazardous

* Incompatible Worlds/Transition Insurmountable

Evolution should be found in the first two categories, and good teachers can place it there for most students. Unfortunately it is more often found in the later categories (especially the last), and much of the blame must be placed on the uninformed, or misinformed, and thus fearful, teacher.

Ebenezer (1996) states that as science educators we must be both aware of, and sensitive to, the "practical arguments" that are based on deeply held religious beliefs. We must assist our students and our teachers in understanding the evolutionary perspectives from both a religious and a scientific worldview.

In fact, several studies have indicated that a conceptual change of this magnitude will force us to modify the theory postulated by Posner et al. (1982). It must be modified to accept the fact that there is rarely a complete abandonment of one concept in favor of another (Gunstone & Northfield 1994). There is almost always the retention of some concepts and an assimilation of others. This surely must be considered when we are dealing with a topic fraught with as much unneeded controversy as evolution.

Fenstermacher (1986) uses the Aristotelian concepts of theoretical and practical wisdom in discussing both conceptual change and the formation of a scientific worldview. He states that there is a definite distinction between the generation of knowledge (theoretical) and the application of knowledge (practical). According to the author, theories end in propositions and assertions, while application ends in action. Teacher educators should ultimately be concerned with the actions of our teachers and how those

actions effect the students in their classrooms.

Perhaps the dichotomy between evolution and creation is accentuated by the confusion between the spiritual, absolute truth associated with the nature of God and the temporal truth of science, both of which are mediated by imperfect human cognition and awareness; again showing the dialectic nature between the very nature of scientific inquiry and the science of evolution. Science should be looked at, not as the pursuit of truth, but as the pursuit of knowledge. Let's leave truth out of it.

The research of Good (1992) identifies four prime factors that influence the teaching and learning of evolution: 1) prior knowledge, 2) attitudes and beliefs, 3) teaching and learning methods, and 4) the nature of the curriculum. All four of these factors were considered in our research project and none stands alone. If we are in hope of true change in our science education system, true reform, each and every one of these factors must be fully addressed in both pre-service and in-service educational programs.

Truly the teacher has a choice. They can ignore the interface between science and religion or they can acknowledge their own personal view as one who has both reconciled the two belief systems and abolished the false dichotomy that exists between them. This is, of course, assuming that this reconciliation has taken place and the abolition has occurred. For teacher educators it is imperative to promote a discussion of these concepts to assist teachers in making this choice.

Cobern (1994) has shown that it is "belief" in an alternative view that prevents our students from accepting the tenets of evolutionary theory. In this regard, one could conclude that the creationist movement has indeed been successful. It could well be argued that curriculum changes in teaching evolution have failed because they failed to recognize that for most students, evolutionary concepts are simply "unbelievable" given their personal world views, which in most cases, include the acceptance of special creation. He feels that, in order to get at the root of the problem, we must ask ourselves the very basic question, "what is the goal for teaching evolution?" [Are we out to] "improve understanding or change belief?" (p. 584). He posits that cultural constructivism demands that we must address the concept of "belief" directly in the classroom if we are ever to hope for an improvement in evolution education. Alter's (1997) agrees by stating that schools have always had belief as a goal of instruction whether implicitly or explicitly expressed.

But surely addressing the concept of "belief" does not mean that we should teach that all beliefs have equal scientific support or are equally valid and sound. As John Dewey (1910) told us almost a century ago, "surely if there is any knowledge which is of most worth it is knowledge of ways by which anything is entitled to be called knowledge instead of mere opinion or guess-work or dogma" (p. 123).

Certainly from the Huxley/Wilberforce "debate" in 1860, through the Scopes Monkey trial in 1925, to today's call for "balanced treatment" or "intelligent design" legislation, evolution continues to be, not only biology's greatest unifying theme and most misunderstood concept, but also the scientific and educational community's lightning rod for public interest.

Although the acceptance of special creation may, in fact, be at the root of our students' (and perhaps our teachers') rejection of evolutionary theory, many researchers have postulated additional, albeit synergistic, hypotheses.

Lawson & Thompson (1988), taking a Piagetian view, argue that evolution is too difficult for elementary, middle, and high school students, who have a tendency to work only at the concrete level and have not reached the level of formal operations. Indeed this may explain why so many of our students (and teachers) seem to follow a Lamarckian rather than a Neo-Darwinian mode of evolutionary change. Falsified over 150 years ago, Jean Baptiste de Lamarck's theory of acquired characteristics--the concept

that changes acquired during an organism's lifetime are somehow transferred into heritable information and passed on to offspring--is perhaps more commonly held as the mechanism of how evolution works, than the more scientifically supported Darwinian concept of variation and selection (Deadman & Kelly 1978; Greene 1990; Jensen & Finley 1996; Firenze 1997B; Settlage 1994). The appeal of a Lamarckian view seems to follow the logic of our everyday experiences where the term "adaptation" is often thought of as a change occurring within the individual organism and primarily due to the use and disuse of structures or through individual needs and intentions. Hallden (1988)concurs and feels that student difficulties with evolution lie in their inability to understand abstract concepts of genetics and how it relates to natural selection.

Jackson et al. (1995) view the teaching of evolution to students with a premature cognitive commitment to the immutability of species as a bona fide example of multiculturalism in education. They state that severe limitations are placed on cognitively oriented conceptual change theory by students who have a profound religious belief in the immutability of species. The authors found that only 29.3% of the college students from the South (their primary area of study) accepted a Darwinian process, while 45.9% see the book of Genesis as the more accurate account. Thus they claim that the two most powerful intellectual trends in education, conceptual change modeling and multiculturalism, make teaching evolution to students of a fundamentalist religious background "futile at best and inappropriate at worst" (p. 587). These students are more interested in learning which is associated with "the good life" rather than learning which is associated with the scientific goal of understanding, explanation, and predictability. These data are corroborated by a recent Harris Poll which shows that 52% of adults from the Northeast accept the fact that "humans developed from earlier species" where only 28% of those from the South answered as such (Harris 2005).

The view of Jackson, et al. is supported by Cobern (1996) who feels that the cognitive change model is based far too much on the rationality of the learner and thus limits the important effects of such concepts as intuition, feelings, and social interactions. In fact, two studies (Bishop & Anderson 1990 and Lawson & Worsnop 1992) are supportive of this indicating that a better understanding of the mechanisms of evolution did not translate into a significant change in students' basic beliefs about evolution. Here it seems that the students comprehended the concept but refused to apprehend its meaning. It is entirely possible the same can be said for many teachers. Smith (1994) warns us that in teaching the scientific basis to evolution we must not design our classes to "make believers lose [their] faith ... [but encourage them to] look carefully at the difference between science and non-science" (p. 596). This, of course, begs the question; are our science teachers truly aware of the differences between science and non-science; and can they accurately convey this difference to their students? It also indicates the strong relationship between the understanding of the nature of science and the accommodation of evolutionary theory.

Pigliucci (2002) argues that American society's slide toward anti-intellectualism in recent years exacerbates the public's failure to accept evolutionary theory. Although certainly not new, the Town & Gown dichotomy has been a staple of many cultures, America has been listing heavily toward the "Townies" since the Reagan administration and most assuredly is mired there with George W. Bush in the Oval Office. Evolutionists are often portrayed by the creationist movement as "arrogant, self-styled experts who disrespect the will of the people" (Pigliucci 2002, p. 94). Of course the same argument was made by William Jennings Bryan as he faced-off with the highly intellectual Clarence Darrow during the Scopes' Trial of 1925.

Other researchers claim the brain was simply not "designed" to understand the complexities of evolutionary theory given its non-intuitive nature. They have argued that the human brain was basically designed to jump to conclusions as a matter of immediate survival value and critical thinking skills occur only when intensely fostered and practiced. (Berns et.al. 2006; Gazzaniga 1998; Jensen 1998; Pigliucci 2002; Pinker 1997 & 2003; Ramachandrian 1998; Lewis-Williams & Pearce 2005). If this is true there is

more than a modicum of irony in the fact that the very process that gave rise to the human brain, natural selection, makes it difficult for that structure to understand its own origin.

Wilson (2005) feels that if we can convince our students and the public of the relevancy of evolutionary theory to human affairs its acceptance will be greatly enhanced. He offers proof of this in his highly popular "Evolution for Everyone" course offered at Binghamton University. Wilson reports that after completion of his onesemester course he sees a "large shift in the positive direction" in his students' views of evolution. This positive shift takes place across both the political and religious spectrum.

In fact recent Pew (2005) and Harris (2005) polls indicate a direct correlation between educational level and the acceptance of evolution. The Harris Poll shows that 32% of those polled with a High School or less education agreed that "Humans Developed from Earlier Species" while 60% of those with a Post-Graduate education responded positively to that question. The Pew Forum reports that 36% of those with a High School or less education feel that "Humans and other living things evolved over time" while 66% of those with a college degree agreed with the statement. Holden (2006) reports that Darwin's place on college campuses is indeed secure if not completely supreme.

Of course these later data do not answer the question whether it was education that lead to the greater acceptance of evolutionary theory or whether those who are predisposed to its acceptance, for whatever reason, seek a higher level of education. As we all know only too well, correlation does not equal causation.

Any and all of the preceding arguments seem plausible as explanations for the roots of evolutionary misconceptions. And certainly all deserve further study.

As scientists and science educators we must identify, assess, discuss, and ameliorate the roots of our misconceptions in light of each of the myriad ideas discussed above. Using all of our talent and resources we must develop methods and materials to effectively convey to our students as well as the American public, the beauty, as well as the limitations, of the scientific process as a reasoned series of arguments open to continuing refinement; and the elegance, importance and relevancy of evolutionary theory to both the scientific and educational communities as well as the general public. It is imperative that this be done without pontificating the arrogance of intellectual certainty.

This accommodation will most definitely not take place until materials and methods are produced that effectively convey to the student the simplicity, elegance, and relevance of evolutionary theory. And most assuredly these materials and methods will be of little use in the hands of teachers who feel little compulsion to use them, have limited skills and knowledge of them, and harbor tremendous misconceptions towards the theory of evolution.

Perhaps if evolution and the nature of scientific inquiry are taught as central themes throughout all life science classes, at all levels, thus allowing our students to accommodate this knowledge as a true scientific concept, Americans will realize Daniel Dennett's (1995) prediction that "In due course, the Darwinian Revolution will come to occupy a similarly secure and untroubled place [as the heliocentric view of the solar system] in the minds -and hearts- of every educated person on the globe" (p. 19).

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Richard F. Firenze, Chairperson, Biology Department, Broome College

Table 1
Perceived Barriers

1) Lack of curricular resources *

2) Lack of access to quality in-service programs *

3) Textbook does not use as theme *

4) Student reluctance/inability to grasp topic *

5) Controversial nature of the topic

6) NYS middle level/regents syllabi & exams *

7) Lack of time in an overcrowded curriculum

8) Lack of adequate academic training *

9) Lack of awareness that theme is recommended *

10) Personal inertia