The "EvoS Effect": The Influence of Evolutionary Training on Critical Thinking Skills

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Abstract

Fostering higher-order cognitive skills (HOCS; e.g., critical thinking and knowledge transfer) are oft-cited goals in education yet are rarely examined as an outcome. In consequence, students do not acquire these skills as much as they could and should. Major efforts in education practice and policy are underway to shift the emphasis in schools toward fostering these habits of mind for lifelong learning. Science education is of particular importance to this revision, as scientific thinking *is* critical thinking. When students develop their skills for science literacy they are learning to think critically; to gather and evaluate evidence so as to develop reliable conclusions that can be further subjected to evaluation. A critical issue in science education today is the teaching of evolutionary theory. Research suggests that science literacy, and therefore critical thinking, can be enhanced by increasing students' understanding and acceptance of evolution. In this study, we provide evidence that a single course that teaches evolution as a theory that applies to all aspects of humanity, in addition to the biological sciences, increases students' acceptance and understanding of both evolution and the nature of science, and, in effect, improves critical thinking performance and domain transfer of knowledge.

Key words: EvoS, Critical Thinking, Knowledge Transfer, Education, Evolution, Science Literacy

Introduction

"Before taking this class, I had no idea how relevant evolutionary theory was to my everyday life."

"This course opened a new way of thinking for me; I now see evolution all around me, from basic human actions to reading history."

"This class revolutionized my way of thinking."

Comments like these actual quotes from students in Binghamton University's (B.U.) Evolutionary Studies courses (EvoS, pronounced as one word: "Ee-vohs") are common at the end of each semester. Dubbed "the EvoS Effect", students regularly report a transformative experience after engaging in their course material. They report being able see evolutionary principles at play in all aspects of their lives thereafter and, being "unable to turn it off", this new framework allows the students to better understand their world; particularly when it comes to the human experience. Moreover, many students report improvements in their problem solving and general thinking skills.

The EvoS Effect is not restricted to Binghamton University or even to EvoS programs at other universities. We predict that it will occur whenever evolution is taught as a theory that applies to all aspects of humanity in addition to the biological sciences. The study presented in this chapter seeks to understand the impact that the EvoS Effect has on learners, to move beyond anecdotal evidence and to begin quantifying the transformative nature of engaging with an evolutionary framework. Presented through the lens of education science, we assert that incorporating an evolutionary studies program into all levels of educational policy and practice can have profound impacts on students' science literacy and, even more so, on their general thinking skills, e.g. critical thinking and domain knowledge transfer.

Background

Fostering higher-order cognitive skills (HOCS; e.g., critical thinking and knowledge transfer) is an oft-cited goal in education yet is rarely examined as an outcome. Until recently the implicit assumption in education practice has been that, with appropriate instruction, thinking skills naturally take care of themselves. In consequence to HOCS being largely left unattended, students do not acquire these skills as much as they could and should. Furthermore, with the emphasis on high-stakes testing, even the most experienced teachers are pressured to rely on rote memorization and the passive application of "learned" algorithms; grades are what count, not learning. In this study, we provide evidence suggesting a science education program rooted in a transdisciplinary evolutionary framework can have a profound impact on fostering HOCS and other habits of mind for life-long learning.

By the very nature of science, science education is well suited for providing a medium through which students can engage in critical thinking. Because scientific thinking is a formalization of critical thinking, it can be used as a model for fostering HOCS at the core of straightforward and easily implemented teaching strategies. If students can develop the skills for science literacy they will know how to think successfully and reach reliable conclusions: abilities valued far beyond scientific and scholarly pursuits.

A critical issue in science education today is the teaching of evolutionary theory. Darwin's theory of evolution is the most powerful explanatory and predictive tool available for the study of living things and the human experience, yet many students receive little or no exposure to this important framework. More so, when it is included in the curriculum, it is primarily taught as a biological topic with little to no application to understanding human affairs.

Three key ideas from science education research informed the study presented in this paper. First, that focusing instruction on nature of science (NOS) skills results in improved reasoning and critical thinking (CT; Abd-El-Khalick & Lederman, 2000a; Akerson, Abd-El-Khalick, & Lederman, 2000; Duncan & Arthurs, 2012; Lederman, 1992; Sadler, 2004; Schwartz, Lederman, & Crawford, 2004). Second, that an improved understanding of evolutionary theory can improve NOS skills (Abd-El-Khalick & Lederman, 2000b; Nickels, Nelson, & Beard, 1996). And third, that using human examples in the teaching of evolution can improve students' understanding (Nettle, 2010). It follows, then, that an EvoS education—a course emphasizing the general applicability of evolutionary theory, with a particular focus on human-related topics—can be expected to improve students' CT and other HOCS.

This chapter begins with a review of the research on CT instruction in current education practice. The focus then shifts to answering three questions regarding improving CT instruction through evolution education: 1) how science education can be used to increase CT; 2) how evolution education can add to science education; and 3) how EvoS education can add to evolution education. Finally, a study is presented that examines the effects of an evolutionary science course, designed to simultaneously foster an understanding of the NOS, on students' CT skills.

Critical Thinking

"We don't know what they will need to know. We do know they will need to be skilled in finding out." ~ Paul & Elder, 2007, pg. 2.

Since the age of Socrates, CT has been recognized as both a major goal of educational systems and a challenge in terms of realization. Despite various nuanced differences in definition, all schools of thought generally concur that "[c]ritical thinking is the art of analyzing and evaluating thinking with a view to improving it" (Paul & Elder, 2006). It is inquiry-oriented and encompasses skills of rational, logical, reflective, and consequential evaluative thinking in terms of what to accept or reject and what to believe in, followed by a decision of what to do or not to do about it (Zoller, 1993). As outlined by Paul & Elder (2006), a well cultivated critical thinker:

- raises vital questions and problems, formulating them clearly and precisely;
- gathers and assesses relevant information, using abstract ideas to interpret it effectively;
- comes to well-reasoned conclusions and solutions, testing them against relevant criteria and standards;
- thinks open-mindedly within alternative systems of thought, recognizing and assess, as need be, their assumptions, implications, and practical consequences; and
- communicates effectively with others in figuring out solutions to complex problems.

Furthermore, research suggests that, while simply developing the specific cognitive skills for CT are indeed necessary, learners must be willing, not just able, to think critically. Consistent willingness, motivation, inclination, and a drive to be engaged in critical thinking while reflecting on significant issues, making decisions, and solving problems is the essence of a disposition toward critical thinking (Facione, Facione, & Giancarlo, 1997; Facione, Giancarlo, Facion, & Gainen, 1995).

Critical Thinking and Domain Transfer of Knowledge

Aside from this general understanding of CT ability, there are a variety of specific skills involved with the CT process. One such skill is the transfer of knowledge across disciplines and domains (Zoller, 1999). Domain transfer takes place when an insight or skill learned in one situation is applied in another situation. As a simple example, if someone has just learned how to calculate the per-kilogram price for almonds, they should then be able to calculate the per-kilogram price for mangoes. If they cannot, we would say that the learning has failed to transfer from pricing almonds to pricing mangoes. A more complex, real-world example of knowledge transfer, more immediately relevant to science education, is when a person who learns the principles of wind flow to design a windmill can transfer that knowledge to direct the sail on a sailboat.

A transfer of acquired knowledge and skills certainly does occur to some extent in education; otherwise, every educational process would require starting from the ground up. The problem is that it happens much less than one might naïvely expect (Detterman, 1993). Failure to transfer knowledge has been repeatedly shown in both laboratory settings and in the classroom (Barnett & Ceci, 2002; Ennis, 1989; Perkins & Salomon, 1988, 1989). This is largely due to the absence of instructional strategies that emphasize incorporating knowledge learned in other subjects into the different classes.

In current education practice, students learn information in one classroom and then learn a separate compilation of facts in their next class, without being encouraged to link the information. What's learned in one classroom may not transfer outside of that class, and what's learned outside the classroom is rarely encouraged to transfer inside the schoolhouse walls. Studies show that children who do complex mathematical calculations in their street business are unable to do the same math problems when presented formally in a classroom situation (Scribner & Cole, 1973, 1981). This is an important finding because "the failure to transfer means the failure to think" (Haskell, 2000, pg. 47).

CT is especially vulnerable to weak transfer skills because CT is "intrinsically general in nature" (Van Gelder, 2005, p. 43). If students fail to transfer learned abilities across domains, then their ability to engage in CT will be severely limited. Nonetheless, transfer is an important component of CT and strategies that emphasize the transfer of learning will benefit general CT skills and vice versa.

Fostering Critical Thinking Skills through Evolution Education

The good news is both the disposition toward CT and CT itself are perceived as being open to educational influence (Brown, 1997), and research suggests that CT can be improved through specific teaching interventions (Abrami et al., 2008; Jensen, 2005/2008; Adey & Shayer, 1990, 1993, 1994; Ernst & Monroe, 2004; Morier & Keeports, 1994; Penningroth, Despain, & Gray, 2007; Wesp & Montgomery, 1998). The research is also clear that this cannot be a matter of implicit expectation; these skills do not develop when direct instructional strategies are absent (Haskell, 2000).

The best instructional approach may be to work simultaneously from both ends: (1) in regular practice of explicit instruction so that skills are exercised, strengthened, and consolidated, and (2) in fostering the understanding and application of the intellectual values ("dispositions") that play a major role when CT skills will be used (Kuhn, 1999). Science education is a natural fit for this two-fold approach to enhancing the development of HOCS—incorporating improved instructional techniques and developing natural dispositions to engage in CT.

Critical Thinking, the Nature of Science, and Science Instruction

Science education has a long list of goals and purposes, nearly all of which center around CT skills (see AAAS, 1990, 1993; Chiappetta & Kobballa, 2009; NRC, 1996, 2012 Zoller, 1993, 1997; Zoller & Tsaparlis, 1997). Scientific thinking *is* critical thinking; when students develop the skills for science literacy, they become naturally engaged in CT practices as they seek to explore and understand the world around them.

Science is not merely a collection of facts, concepts, and useful ideas about nature. Science is a method of investigating nature that discovers and examines reliable knowledge about it. Science education should emphasize the importance of educating students to encourage their curiosity about the world in which they live so that they ask questions about its nature and address those questions through their investigative actions (NRC, 1996, 2012).

One key aspect of science instruction that naturally reinforces HOCS while simultaneously emphasizing content-related curriculum goals is through an increased attention on the Nature of Science (NOS). The NOS consists of those seldom-taught but very important features of working science, e.g., its realm and limits, its levels of uncertainty, its biases, its social aspects, and the reasons for its reliability (AAAS, 1990). When students develop the habits of mind that stress the useful values, attitudes, and skills for understanding the world around them they are developing the fundamental understanding about the NOS.

Although many states include NOS in their science standards, students often have misconceptions about it, and some science teachers share these misconceptions (e.g., Carey & Smith, 1993; Dagher & BouJaoude, 2005; Lederman, 1992; Scharmann & Harris, 1992; Solomon, Scott, & Duncan, 1996). Science is often misrepresented in the media, and classroom teaching can overemphasize what we know rather than how we know it. Consequently, many students see science as a boring enterprise – the tedious accumulation of facts about the world, totally lacking any imagination or creativity. Many students believe that theories can simply be "read off" from the world, that scientific claims can be definitively proved, and that theories are merely speculative guesses without much empirical investigation supporting them and have therefore not yet achieved the privileged status of facts or laws. These misconceptions may be aggravated by teaching what textbooks usually call "*the* scientific method": a linear sequence of steps suggesting scientists follow a single, fixed process to develop laboratory experiments that directly and definitively test hypotheses. Confronting these misconceptions is the first step toward developing a scientifically literate population, one that can think rationally and critically.

Furthermore, an increased understanding of the NOS assists in developing a foundation for transfer skills. As any decent education in science requires that the student come to understand the central role of theory[1] in scientific methodology, students are encouraged to seek

[1] As a coherent group of general propositions that are used as principles of explanation for a class of phenomena.

an understanding between relationships and to draw on similarities and differences across many fields of knowledge. An emphasis on the role of theory in science allows students to acquire sound conceptual knowledge about their world through the formulation of relationships among ideas (Ausubel, 1963).

When students, and teachers, understand the NOS (AAAS, 1993, Ch. 1) and "Science as a Way of Thinking" (AAAS, 1993, Ch. 12), they are automatically entered into a world of CT and knowledge transfer. Research in the laboratory and classroom confirms that focusing instruction on NOS skills results in improved reasoning and CT (Abd-El-Khalick & Lederman, 2000a; Akerson, Abd-El-Khalick, & Lederman, 2000; Duncan & Arthurs, 2012; Lederman, 1992; Sadler, 2004; Schwartz, Lederman, & Crawford, 2004). In no other curriculum is the demand for CT and other HOCS as important for success as it is in science education.

Nature of Science Instruction, Evolution and Knowledge Transfer

Amongst the chief aims of increasing science literacy, and therefore CT, is developing an increased understanding of evolutionary theory (Rudolph & Stewart, 1998). Generic scientific reasoning existed before Darwin but was insufficient by itself to achieve insights about the living world. By unlocking the theory of evolution by natural selection, Darwin opened a realm of understanding unforeseen by any other scientific accomplishment at the time; causing one scientist to famously remark: "nothing in biology makes sense except in the light of evolution" (Dobzhansky, 1973).

Evolution is recognized as a unifying principle for understanding biological phenomena and provides a coherent framework for organizing biological knowledge and thinking; making an impressive degree of knowledge transfer possible within the biological sciences. What's less understood about evolution is its transferability to domains beyond biology. Evolution is recognized as a common theme of science[2] that transcends disciplinary boundaries (see AAAS, 1990, Ch. 11; AAAS, 1993, Ch. 11; NRC, 1996, Ch. 6; NRC, 2012, Ch. 4); most importantly, for understanding a panoply of human-related behaviors (Wilson, 2007). By applying the principles of evolutionary science to the thinking about other subjects, students can improve CT by transferring their understanding of evolutionary theory to a diverse range of topics.

Research indicates that NOS instruction can be enhanced through a thorough investigation of evolutionary theory in the curriculum (Abd-El-Khalick & Lederman, 2000b; Nickels, Nelson, & Beard, 1996). Thus, the effects of a course on evolution are two-fold. First, students are able to identify and understand their previously held misconceptions about evolutionary theory. And second, by investigating the major claims of evolutionary science, students must apply the habits of mind for scientific thinking, developing an increased understanding about the NOS while fostering CT. So, it stands to reason that a course on the domain general applicability of evolutionary theory can be expected to have an impact on

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[2] "Some important themes pervade science, mathematics, and technology and appear over and over again, whether we are looking at an ancient civilization, the human body, or a comet. They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design" (AAAS, 1993, p. 261). The American Association for the Advancement of Science (AAAS, 1990; 1993) identifies four Common Themes of Science: Systems; Models; Constancy & Change [Evolution); and Scale. The National Research Council (NRC, 1996) identified five Unifying Concepts in their 1996 National Science Education Standards: Systems, order, and organization; Evidence, models, and explanation; Change, constancy, and measurement; Evolution and equilibrium; and Form and function. A recent re-envisioning of the NRC Unifying Concepts has resulted in a new framework for the Next Generation Science Standards (NRC, 2012) with seven Crosscutting Concepts: Patterns; Cause and effect; Scale, proportion, and quantity; Systems and system models; Energy and matter: Flows, cycles, and conservation; Structure and Function; Stability and change [Evolution]. Though different in quantity and specific titles, each of these views are congruent with the important impact of ideas that transcend disciplinary boundaries for a comprehensive understanding of NOS.

students' understanding and incorporation of the NOS, and that this course can directly impact CT skills.

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The next section provides an overview of the status of evolution education today and then describes how a single course, Evolution for Everyone (as taught through the B.U. EvoS), can be designed to overcome these challenges. Finally, the actual effects that this course has on students' understanding about evolutionary theory, the NOS, and their CT skills will be examined.

The Current State of Evolution Education

Darwin's theory of evolution is the most powerful explanatory and predictive tool available for the study of living things (Darwin, 1859, 1871; Coyne, 2009; Dawkins, 2009; Miller, 1999; Wilson, 2007). Evolution is accepted and supported by all reputable scientists and new evidence surfaces daily to support its explanatory power. Yet, many students receive little or no exposure to this important concept (Lerner, 2000). Fewer than 50% of Americans accept evolution (Miller, Scott, & Okamoto, 2006). People and groups opposed to the teaching of evolution in the public schools have pressed teachers and administrators to present ideas that conflict with evolution or to teach evolution as a "theory, not a fact." And this cultural movement giving rise to this nonscientific worldview in America has also been gaining strength in other countries (see PACE, 2009 for a summary of such events in Europe).

The effect these movements have had on evolution education is unsettling. These attitudes have contributed to widespread misconceptions about the state of biological understanding specifically, and more generally about what science is and is not. Even worse is a second wall of resistance: amongst those who do accept evolution as a suitable framework for unifying biological knowledge, many don't relate the importance of evolution to the human species. There is a divide within academia regarding the theory's transferability to human affairs and evolution is still taught primarily as a subject in the biological sciences rather than as a theory that can help to unify the human-related disciplines (Ehrenreich & McIntosh, 1997).

Nonetheless, each of these walls of resistance can be surmounted through a course properly designed to increase the acceptance of evolutionary theory through an increased focus on the NOS. Research has demonstrated that understanding the nature of science may be correlated with accepting evolution for both students (Lombrozo et al., 2008; Verhey, 2005; Woods & Scharmann 2001) and high school biology teachers (Rutledge & Mitchell, 2002; Rutledge & Warden, 2000; Scharmann & Harris, 1992; Trani, 2004). And there is some suggestive evidence that learning about NOS can increase acceptance of evolution in teachers (Scharmann & Harris, 1992) and in students (Verhey 2005). In one study, acceptance of evolution in secondary school teachers increased after a workshop that focused on scientific theory and evolution (Scharmann & Harris, 1992). A course developed at Binghamton University is specifically designed to accomplish this goal and stands as the introductory course for the University-wide Evolutionary Studies program.

Evolutionary Studies at Binghamton University

Binghamton University's (B.U.) Evolution for Everyone course is the introductory course for the university's EvoS program, a comprehensive, transdisciplinary effort to teach evolution as part of a scientific approach to all human-related subjects in addition to the biological sciences (O'Brien & Wilson, 2010; O'Brien, Wilson, & Hawley, 2009; Wilson 2005, 2007).

The basic mission of an EvoS program is to expand evolutionary theory beyond the biological sciences, to reach as many students as possible early in their academic careers, and to provide a multicourse curriculum so students can continue their training throughout their academic careers. The courses in B.U.'s EvoS program are designed to not only teach evolutionary theory but to specifically emphasize the transfer of evolutionary concepts across domains to enhance students' understanding of human-related knowledge. Initiated in 2003, it has become the basis of a nationwide consortium of programs funded by the National Science Foundation (http://www.evostudies.org/) that currently includes groups from over 25 institutions.

The cornerstone of an EvoS program is an introductory "Evolution for Everyone" course that immerses students from all backgrounds and academic disciplines in both evolutionary theory and the scientific process. The course has proven successful at influencing the acceptance and understanding of evolutionary theory in students from the sciences and the humanities (O'Brien, Wilson, & Hawley, 2009; Wilson, 2005), and has demonstrated success at reaching students across a multitude of political and religious backgrounds. Here, we continue an investigation of this course by studying the effects of "evolutionary training" on students' CT skills.

Methods

The Course: Evolution for Everyone

B.U.'s version of "Evolution for Everyone" (E4E, hereafter) is a large (approximately 170 students) introductory-level biology course that has no prerequisites and satisfies general education requirements. The course is cross-listed by the biology and anthropology departments, reflecting its emphasis on both biological and human-related topics. Although a 100-level course, it is popular among students from all class levels and a diverse range of majors (see Table 1). The basic design of the course includes the following features:

- A large lecture course that provides students from any background with a firm knowledge of the mechanisms of evolution.
- A strong focus on the application of evolutionary theory to human affairs.
- A curriculum that is structured to highlight NOS and the scientific habits of mind. This includes both in-class experiments and a final project that requires the students to propose novel research on topics of their own choice. Basic statistics are also taught through analyses of in-class experiments and evaluating evidence from the literature.
- The course goes beyond lecture mode, incorporating active, in-class demonstrations, discrepant events, and other "minds-on" activities on a regular basis; as well as cooperative discussions and brainstorming tasks.
- A before-and-after assessment (Hawley, Short, McCune, Osman, & Little, 2011) that has demonstrated a positive effect on both the students' knowledge of evolution and their attitudes towards its relevance.
- In addition to bi-weekly lectures, students also attend smaller weekly activity/discussion sessions run by undergraduate teaching assistants.
- Exams are take-home essay format, which allows students to fully digest the course material, emphasizing the application of principles being learned.

The format of the course involves teaching the basic principles of evolution during the first part of the semester, which is then applied to a diverse range of biological and human-related subjects over the rest of the course. This format became the basis of a book by the same name (Wilson, 2007), which is now used as the textbook with supplementary reading from the primary literature.

For additional details about B.U.'s EvoS program, the course curriculum, and examples of instruction style, we direct the reader to the following sources: O'Brien & Wilson, 2010; O'Brien, Wilson, & Hawley, 2009; Wilson, 2005.

Participants

Participants were students in B.U.'s Fall 2011 E4E course. Of the 182 students enrolled in the course, only 108 completed both surveys at times one and two (T1 and T2). These discrepancies are in part due to the university's add-drop period, which extends two weeks into the semester

There were 44 males and 64 females, and the population represented a wide variety of majors and academic standings (Freshman, Sophomore, Junior, Senior). As religious affiliation is frequently posited as a major hurdle to evolution education, religious affiliation was also identified. Demographic information is reported in Table 1.

Measures

Assessing Course Goals with the Evolutionary Attitudes and Literacy Survey

Since the hypothesis being tested in this paper claims that students who develop a greater understanding of evolutionary theory will have improved CT performance, the overall efficacy of the course at teaching the evolutionary perspective and the NOS were assessed first to determine whether the course was successful in this task. Outcomes were assessed by way of the Evolutionary Attitudes and Literacy Survey (EALS; Hawley, Short, McCune, Osman, & Little, 2011), which was administered at the beginning[3] and end of the course via an anonymous online

[3] From one week before the first day of classes to the beginning of the second day of class.

survey made available to enrolled students. Participation was voluntary and all methods were approved by B.U.'s Institutional Review Board.

The EALS is comprised of 12 scales assessing various belief systems (e.g., religious), attitudes (e.g., about the relevance of evolutionary theory), knowledge of biological topics (i.e., genetics), and science literacy (used as a measure for NOS understanding). The scales were as follows: Attitudes Toward Life, Intelligent Design Fallacies, Young Earth Creationist Beliefs, Moral Objections to Evolution, Social Objections to Evolution, Distrust of the Scientific Enterprise, Relevance of Evolutionary Theory, Genetic Literacy, Evolutionary Knowledge, Evolutionary Misconceptions, Knowledge about the Scientific Enterprise, and Self-exposure to Evolution (items and scale reliabilities reported in Appendix). Responses to each scale item were measured using a 7-point Likert scale from "strongly disagree" to "strongly agree," the center point ("4") representing "neither agree nor disagree." Scores for each of the EALS scales were calculated as a mean of the items in that scale. In addition to assessing beliefs, knowledge, and attitudes, the survey assesses a wide range of background demographic information including political and religious activity and affiliations, intended major, class level, and experience with courses teaching evolution during college and high school.

Correlations and interactions between EALS scales have already been analyzed in previous reports (O'Brien, Wilson, & Hawley, 2009) and relationships between changes in these scales and participants' backgrounds will not be a focus of this study. The EALS is included in this analysis in order to determine whether an "EvoS Effect" can be expected in the study population; in other words, whether the students sufficiently incorporated a deeper understanding of evolutionary theory and the NOS which, according to the hypothesis presented in this paper, should carry over to an increase in CT skills.

Assessing Critical Thinking

The literature identifies two primary modes of analyzing CT: 1) a componential assessment, which employs standardized CT questions (e.g., Facione, Facione, & Sanchez, 1994) that rely largely on formal or informal logic to individually assess specific components of what is generally considered to be CT—e.g., inference, induction, deduction, interpretation, analysis, etc.; and 2) a more holistic approach that utilizes rubrics as an assessment strategy, allowing for the analysis of CT in more-general open-ended responses (Paul & Elder, 2007). Because students in E4E regularly participate in surveys and in-class experiments, this study utilized the latter of these two methods of CT assessment to reduce survey fatigue (Porter, Whitcomb, & Weitzer, 2004).

CT was analyzed with a separate pre-/post-course survey, also administered during the first and last weeks of the course. Each survey consisted of six questions that were designed by the researchers to encourage a critical evaluation of a given topic. The survey questions asked students to reason about situations in the biological sciences and situations from human-related topics. This approach was selected to test students' application of CT and the near-transfer of learning to a subject that is typically presented in line with evolutionary theory (i.e., biology), while also testing CT and the far-transfer of evolutionary principles to an area where evolution is less prominent (i.e., the social sciences and human-related affairs).

Eleven questions were designed: five questions related to biological scenarios and six questions concerning situations regarding the human condition (reported in Table 2). The questions were randomly assigned to pre- and post-test conditions. Each survey was composed of three questions from the biological category (*Bio*) and three questions from the social sciences (*SS*). One question was repeated on both surveys ("*Carnivores*") to examine differences in responses between survey administrations within a single question. Students were asked to answer each question with three to five sentences and were not otherwise primed to execute CT.

Measuring Critical Thinking with Lexical Content Analysis

CT survey responses were first analyzed with the Linguistic Inquiry and Word Count text analysis program (LIWC, pronounced "Luke"; Pennebaker & Francis, 1996, 1997) in order to identify potential differences in CT between T1 and T2. LIWC analyzes text files and computes 61 language dimensions, each presented as a percentage of total words. Analyses in this study focused on the cognitive mechanism parameters: insight (i.e., *think*, *consider*), causation (i.e., *because*, *effect*), discrepancy (i.e., *should*, *could*), tentativeness (i.e., *maybe*, *guess*), certainty (i.e., *always*, *never*), inhibition (i.e., *block*, *constrain*), inclusion (i.e., *and*, *with*), and exclusion (i.e., *but*, *without*). These parameters have been used in prior studies of critical thinking (Carroll, 2007; Pennebaker, Mayne, & Francis, 1997; Pennebaker & Seagal, 1999). Because LIWC identified significant differences in the use of cognitive mechanisms between T1 and T2 (as detailed below, also see Table 3), a more thorough investigation of CT responses was conducted by employing independent raters to score each response according to a rubric. This rubric and the scoring process are described in the next section.

Measuring Critical Thinking by Independent Raters

Developing the Critical Thinking Rubric

The rubric used in this study was a modified version of the Association of American Colleges & Universities (AAC&U) Valid Assessment of Learning in Undergraduate Education (VALUE) Critical Thinking rubric (Rhodes & Finley, 2013; available at http://www.aacu.org/VALUE/rubrics/). A modified version of the VALUE rubric was developed because, in its original form, the rubric is designed to be used with text passages that are composed of multiple paragraphs. Since our questions were designed to be answered in only 1-2 paragraphs, the VALUE rubric was modified to be more applicable to the short-answer questions developed for this study. The finalized rubric is provided in Figure 1.

Rating Response Sets

Scoring of the survey responses for CT was performed by three independent raters. All raters were unaffiliated with the course and B.U.'s EvoS program, and remained naïve to the experimental aims. Meetings were conducted in the university library, a neutral location so as to remain unbiased to the departmental "home" for this study. Prior to scoring experimental responses, the raters were given a program of training, which included background reading about measuring CT, a four-week orientation to the rubric, calibration sessions and scoring practice, and discussions of several samples that represented the whole range of possible results.

Inter-rater reliability of CT scores was calculated using Krippendorf's alpha (Hayes & Krippendorf, 2007) for each of the CT components (*Approach*, *Logic*, *Evidence*, and *Conclusion*) and the combined sum of component scores for each question (*Sum*). Every component yielded moderate to high measures of inter-rater reliability, except for three *Evidence* scores and one *Conclusion*. All values are reported in Table 2.

The low reliability of *Evidence* scores is, in part, the result of very low scores in this category overall. Most responses were scored as "0" for this category, as they were identified to contain no evidence or examples and so a single discrepancy greatly influenced the reliability calculation. For example, of the 166 responses collected for the *Newspaper* question, the *Evidence* scores ($\alpha = .20$) for each rater were: Rater 1 - 163 responses scored "0" and 3 responses scored "1"; Rater 2 - all 166 responses scored "0"; Rater 3 - 161 scored "0", 3 scored "1", and 1 response scored "2." Given this pattern of ratings and given that the reliability of the *Sums* scores for every question yielded high reliabilities, all scores were retained for further analysis.

Because nearly all scores demonstrated high reliability between raters, mean scores were calculated for each question on each of the individual components (*Approach*, *Logic*, *Evidence*, and *Conclusion*) and for the total *Sums*. Scores from the pre-test condition were combined into a pre-test (T1) mean score for the biological questions (*Bio)*, social sciences questions (*SS*), and a total pre-test score (*Combined*). Similarly, a post-test (T2) mean score was calculated for each of these categories – *Bio*, *SS*, and *Combined*.

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It is important to point out that answers were scored for the inclusion of CT skills and not for correct answers. Independent raters were not provided an "answer key" nor was there a discussion of "correct" answers during the norming sessions. This was done in order to prevent bias in response ratings, as an incorrect answer could still demonstrate good CT skills.

Assessing Transfer of Learning

To test for transfer of learning, each response from the CT survey was evaluated for the incorporation of evolutionary principles by a fourth independent rater. Responses were considered to incorporate an evolutionary perspective if they included any of the following key terms with appropriate application of the principles: adapt, adaptation, drift, evolution, evolve, evolutionary, fitness, selection, trade-off, mismatch, byproduct, and variation. For this reason, this fourth independent rater was selected from B.U.'s EvoS population, as knowledge of evolutionary principles was required for accurate assessment.

Responses incorporating evolutionary reasoning into their answers were scored as "1," while answers which did not directly employ an evolutionary perspective were scored as "0." Responses containing key terms but lacking an obvious evolutionary rationale were not considered cases of knowledge transfer. Total pre- and post-test transfer scores were calculated for each participant as a sum of each score in the individual categories—*Bio* and *SS*, and for the *Combined* scores.

Results

Analysis of Evolutionary Attitudes and Literacy Survey

A paired samples *t*-test of scores between T1 and T2 of the EALS revealed a greater understanding of evolutionary theory and its general applicability beyond the confines of biology. Scores also reflect a better understanding of the NOS. Mean scores for T1 and T2 are reported in Table 3.

Students reported a significant increase in understanding the *Relevance of Evolutionary Theory* ($t(106) = 3.119$, $p = .002$), and a decrease in *Evolutionary Misconceptions* ($t(105) =$

-2.492, $p = .014$). Students also reported an increase in their *Self-exposure to Evolution* ($t(106) = 5.020$, $p < .001$), suggesting their willingness to further increasing their understanding of evolution outside of any class requirements. Students also reported a marginally significant increase in *Evolutionary Knowledge* ($t(105) = 1.931$, $p = .056$).

This demonstrated increase in students' knowledge of evolutionary theory was accompanied by a decrease in beliefs that typically contend with evolutionary thinking. Students reported a decrease in beliefs regarding *Social Objections to Evolutionary Theory* ($t(106) = -2.627$, $p = .010$), and a decrease in *Intelligent Design Fallacies* ($t(105) = -3.002$, $p = .003$); accompanied by reported, however non-significant, decreases in the *Moral Objections to Evolutionary Theory* ($t(106) = -1.515$, $p = .133$), and decreased *Young Earth Creationist Beliefs* ($t(106) = -1.672$, $p = .098$). Though differences between T1 and T2 in *Moral Objections* and *Young Earth Creationist Beliefs* were not significant, they are still important to include as an analysis of the overall trend of differences from the beginning to end of the semester.

Regarding NOS measures, while *Knowledge of the Scientific Enterprise* did not increase ($t(105) = 0.489$, $p = .626$), students reported a decrease in their *Distrust of Science* ($t(106) = -4.080$, $p < .001$). Future studies would benefit with the inclusion of a direct measure of knowledge about the NOS but these current scales serve the function of identifying an improvement in student's general understanding about the NOS.

Religious and political attitudes were generally unaffected, however students reported a significant increase in *Conservative Self-Identity* ($t(106) = 2.327$, $p = .022$). Further implications regarding political and religious affiliations will be discussed elsewhere, as they are outside the scope of this study.

The pattern of results presented here demonstrates that students sufficiently incorporated a deeper understanding of evolutionary theory and the NOS through participation in the course. Therefore, an analysis of CT skills was conducted to examine if this "EvoS Effect" carries over to an increase in CT skills.

Analysis of Critical Thinking

Analysis of Critical Thinking with Lexical Content Analysis

Table 4 presents the results of a paired samples *t*-test between LIWC scores from T1 and T2 for each of the cognitive mechanisms (*Insight*, *Discrepancy*, *Tentative*, *Certainty*, *Inhibition*, *Inclusive*, *Exclusive*). Results revealed significant differences between scores in all categories of cognitive mechanisms except *Exclusive*. At T2, students were more likely to include words expressing *Causation*, *Inhibition*, and *Inclusion*. They were less likely to include words expressing *Insight*, *Discrepancy*, *Tentativeness*, and *Certainty*. Implications of these results will be interpreted in the discussion section.

While LIWC can identify differences in the use of cognitive terms, these results do not lend themselves to an interpretation for assessing any increase or decrease in CT—they merely suggest that a difference could exist based on word use. An analysis of response scores by the independent raters was conducted to examine the quality of CT in the survey responses.

Analysis of Critical Thinking Scores Assigned by Independent Raters

Paired samples *t*-tests between CT scores from T1 and T2 were run for each CT component and the sums of CT scores for the *Bio* questions, *SS* questions, and the *Combined* questions. Paired samples *t*-tests were also performed between the pre- and post-test scores on the individual *Carnivores* question, so as to measure the differences on a single item between T1 and T2. Full results are presented in Table 5; Figure 2 displays the scores of CT pre and post *Sums* for each question set (i.e., *Carnivores*, *Bio*, *SS*, and *Combined*).

Beginning with the repeated-item *Carnivores* question, results of a paired samples *t*-test indicate that students scored higher on overall CT at T2 than at T1 (*Sum*: $t(96) = 3.200$; $p = .002$). Analysis of individual CT components attributes this improvement in overall CT to a better *Approach* to answering the question ($t(96) = 4.753$, $p < .001$), and by including better *Evidence* to justify their claims ($t(96) = 2.762$, $p = .007$).

Results for *Bio* questions, *SS* questions, and the *Combined* questions also demonstrated increased CT scores at T2. Students demonstrated the largest increases in CT on the *SS* responses, and improved on every dimension except for *Evidence* ($t(107) = 0.107$, $p = .915$). Interestingly, the least impressive of these results was in the *Bio* questions, where only *Approach* resulted in a significant increase from T1 to T2 ($t(105) = 3.233$, $p = .002$), and students actually wrote worse conclusions to their responses at T2 for the *Bio* questions ($t(105) = -2.018$, $p = .046$). Figure 3 displays the scores of CT components in the *Bio* and *SS* responses.

In the *Combined* question sets, students demonstrated an overall significant improvement on all components of CT except for *Approach* ($t(107) = 1.909$, $p = .059$; marginal significance) and the inclusion of *Evidence* ($t(107) = -0.408$; $p = .408$).

Analysis of Knowledge Transfer

The transfer of evolutionary principles was analyzed for the repeated-item *Carnivores* question, and for the combined *Bio* questions, *SS* questions, and the *Total* response set. Prior to a comparison of the scores between the pre- and post-test conditions, the scores of the *Bio* and the *SS* questions were compared with each other to identify the likelihood of students incorporating evolutionary principles into responses from each of these domains. Results of a paired samples *t*-test revealed that at T1 students were more likely to apply evolutionary principles in their responses to biological topics (*M* = 0.30 (*SD* = 0.52)) than in the social sciences (*M* = 0.13 (*SD* = .39); *t*(107) = -2.732, *p* = .007). This bias was no longer present at T2, where students were equally as likely to apply evolutionary reasoning into their responses for the *SS* questions (*M* = 0.43 (*SD* = 0.69)) as they were for the biological questions (*M* = 0.51 (*SD* = 0.63); *t*(107) = -1.174, *p* = .243). Figure 4 displays these differences between *Bio* and *SS* transfer scores at T1 and T2.

Following this preliminary analysis, scores between T1 and T2 were compared. Analysis of the single-item *Carnivores* question did not reveal a significant difference between the inclusion of evolutionary principles in students' responses between T1 and T2 (*t*(96) = -0.241, *p* = .810). However, when comparing the full sample of responses, results revealed that students were more likely to incorporate an evolutionary explanation at the end of the semester than they were at the start (*t*(107) = 4.783, *p* < .001). This result was demonstrated in both the biological questions (*t*(107) = 2.859, *p* = .005) and the human-related questions (*t*(107) = 4.573, *p* < .001). Results are reported in Table 6.

Discussion

Three important ideas from science education research informed this study. First, that focusing instruction on understanding the Nature of Science (NOS) results in improved reasoning and critical thinking (CT). Second, that an improved understanding of evolutionary theory can improve NOS skills. And third, that understanding evolution can be improved by focusing instruction on humans. Thus, this study sought to test the hypothesis that a course emphasizing the general applicability of evolutionary theory should be expected to improve CT, particularly by way of increased knowledge transfer.

Discussion of Evolutionary Attitudes and Literacy Survey

Evolution for Everyone (E4E), B.U.'s introductory EvoS course, is a course that is designed explicitly around these themes. Results of the EALS confirmed that participation in the course decreased students' misconceptions about evolution and NOS, and reduced students' reports of holding conflicting beliefs against evolution. With the EALS serving as a confirmation that these stated aims of the course had been achieved, we then proceeded to examine how receiving this "evolutionary training" impacted students' CT skills, and if this "EvoS Effect" transfers across subject domains.

Discussion of LIWC Results

Through a lexical content analysis of survey results, responses were found to differ significantly between T1 and T2 in the use of words related to cognitive mechanisms, the categories most directly related to CT. Of the cognitive mechanisms, the most direct connection to CT is in the *causation* (i.e., because, hence) category. After participation in E4E, students used higher frequencies of words related to *causation* when answering the CT survey questions, indicating more thoughtful cause-and-effect responses.

Interpretations of the other cognitive mechanisms categories are slightly less straightforward. After the course, students were less *tentative* (i.e., maybe, perhaps) in their responses which would typically indicate that they had higher certainty in their answers but LIWC results also indicate that students were less-likely to use words indicating *certainty* (i.e., always, never). This pattern of results could indicate that while students were more confident in their answers they were also less-likely to speak in absolute terms, allowing more flexibility and open-mindedness (a characteristic associated with CT). The decrease in *insight* (i.e., think, consider) scores may indicate that students had more knowledge-informed responses and did not need to speculate as much in their explanations after participation in the class as they did at the beginning.

While LIWC is able to identify differences in the lexical content of writing samples, the program is unable to assess the contextual quality of the responses. Therefore, any assessment of CT from LIWC results is only speculative. The purpose of incorporating LIWC analysis here serves as a preliminary assessment as to whether differences in CT could be expected with a more thorough investigation. Because LIWC results did identify significant differences in the use of cognitive terms between T1 and T2, the researchers proceeded to investigate the quality of responses for differences in CT.

Discussion of Critical Thinking Assessment

A comparison of the scores assigned by naïve raters indicated a significant improvement in CT (*Sums*) at the end of the semester. Of the CT categories scored by the raters, the largest improvements were observed in students' Development of Argument (*Logic*) and the formulation of *Conclusions*.

Overall, students showed very little improvement in the incorporation of evidence/ examples into their responses. This is not surprising since students were not permitted to look up information when answering the questions and the instructors intentionally avoided any conversations about these specific topics during the semester. Therefore, students were not necessarily equipped with sufficient background knowledge to incorporate specific examples for each question. Nonetheless, even without knowing any exact details of the situations presented in each question, students were better able to rationalize a meaningful response at T2, demonstrating the impact of presenting evolutionary theory as a general explanatory framework that can be integrated with knowledge across subject domains.

When the questions were analyzed by topic—biological or human-related questions, students demonstrated the largest improvements in their responses to the human-related questions. This suggests that, while a course on evolutionary theory improved overall CT on all questions, it provided a valuable new framework for organizing thinking about human affairs—an area where students are not typically encouraged to incorporate evolutionary thinking in their other courses.

Evolutionary Training and the Transfer of Learning

Beyond the assessment of general CT skills, this study specifically sought to examine the effect that evolutionary training has on domain transfer of learning. The transfer of learned information from one context to another is an overarching goal in education, and is a basic requirement for CT (Perkins & Salomon, 1988; Zoller, 1999). However, much research has demonstrated that students often fail to apply knowledge and skills learned in one context to other situations (Detterman, 1993; Ennis, 1989; Perkins and Salomon, 1989). One of the key explanations behind this disconnect is that the current emphasis on content-specific instruction and assessment leaves little room in curriculum-instruction-assessment practices for incorporating cross-cutting concepts. Content-specific instruction is not optimal for teaching students to transfer more abstract critical thinking skills across domains (Halpern, 1998). Evolutionary theory is distinctive in this regard, wherein a course that emphasizes increasing an understanding of evolutionary content can simultaneously extend the principles across examples from a wide variety of domain contexts in order to reinforce the general applicability of the theory.

Our results show that prior to participation in the course students were far more likely to apply evolutionary reasoning to questions about biological topics than they were to apply an evolutionary framework to human-related situations. This bias was no longer present after participating in E4E, and students were equally likely to incorporate evolutionary reasoning for the social science questions as they were for questions about biology.

A comparison between T1 and T2 responses revealed an overall increase in the application of evolutionary principles after participation in the course. And, like the results described for CT, the largest increase in the application of evolutionary theory was observed in the questions related to human affairs. This pattern of results demonstrates that students were not only more inclined to explain biological situations from an evolutionary perspective after taking an evolutionary science course but also that students were inclined to transfer evolutionary principles across disciplines, deepening their understanding of human-related issues.

Limitations

The study presented here provides evidence that a single course on evolutionary theory which is designed to simultaneously emphasize a deeper understanding of the NOS can have considerable impact on students' CT skills. More work must be done to further investigate these effects. At this time, the design of this study cannot discriminate whether the observed improvements can be attributed to either the learning of a domain-general evolutionary perspective or to the increased understanding of the NOS, or whether they operate in unison.

Also, the assessment did not include a comparison with another course. This is in part because it is difficult to know what an appropriate control group would be. Nonetheless, this study would benefit from further investigation of these results.

A second limitation of this study that arises from the absence of a comparison group is in considering the general increase of CT during the course of routine college participation. Since most disciplines and general education classes stress critical thinking, it is reasonable to suggest that these measures could improve over any semester in the absence of evolutionary training. However, where improving CT is a widely-reported aim for most college and university programs, research has revealed that this goal often remains unrealized (Arum & Roska, 2011; Roksa & Arum, 2011). A study that followed 2,322 traditional-age students from the fall of 2005 to the spring of 2009 and examined testing data and student surveys at a broad range of 24 U.S. colleges and universities revealed that 45 percent of students made no significant improvement in their CT, reasoning or writing skills during the first two years of college. After four years, 36 percent showed no significant gains in higher-order thinking skills.

While more work is needed with appropriate control groups to fully investigate the general trajectory of CT development of students with and without evolutionary training, we further analyzed the results to speak to some of the implications associated with this concern: If most classes are designed to enhance CT skills, one might suspect that this increase would be greater for first semester freshman when compared to upperclassmen. A comparison of CT results revealed no significant differences between class standing (i.e., freshmen, sophomores, juniors and seniors) in both the pre-assessment ($F(3,100) = .866$, $p = .461$) and post-assessment scores ($F(3,100) = .140$, $p = .936$). Seniors scored the lowest in CT at the start of the semester ($M =$

5.65, *SD* = 0.86) and showed the greatest overall improvement at T2 (*M* = 6.24, *SD* = 0.90), followed by freshmen (T1: *M* = 5.92, *SD* =_1.16; T2: *M* = 6.33, *SD* = 1.16), sophomores (T1: *M* = 6.05, *SD* = 0.62; T2: *M* = 6.21, *SD* = 0.98) and juniors (T1: *M* = 6.15, *SD* = 1.20; *M* = 6.33, *SD* = 1.30). This pattern of results reveals that CT skills improved as much for upper-classmen as they did for freshmen, providing further support for a specific EvoS Effect in this sample.

Perhaps the most suggestive results from this study are those that demonstrate that students increase the transfer of evolutionary principles to domains beyond the biological sciences—a practice that is uncommon with traditional evolution instruction. This could also be improved with further research that tests a population of past students (and a comparison group) in a manner which does not have any direct connection to an evolutionary science course. In the current methodology, students may have been primed to answer with evolutionary thinking since the survey was disseminated in connection to the class. However, in support of the conclusions drawn from this study, both the pre- and post-tests were provided as voluntary research participation through the course and any priming for evolutionary thinking would be present at both times. With these priming effects being equal, the observed results can be considered a reliable demonstration of improvement in the transfer of evolutionary principles across domains.

Conclusion

The theory of evolution is impressive, productive and important. To become a serious biologist, one needs to have a grasp of what a domain-general evolutionary theory means. To be an informed citizen, one should have a general understanding of not only what the theory claims but of how those claims are substantiated through scientific methodology. If students master an understanding of evolutionary thinking they will know how to think successfully and reach reliable conclusions; such ability will prove valuable in any human endeavor. The results presented here demonstrate that a single course on evolutionary theory that stresses evolution across domains increases students' acceptance and understanding of evolution, the NOS, and, crucially, CT performance.

It is striking, and worth emphasizing, that a traditional evolution education does not produce the EvoS Effect. Traditionally, evolution has been treated as a short, stand-alone unit in the biology curriculum, rather than a unifying theme that can improve understanding across the entire discipline. Sometimes, this topic is skipped entirely (Berkman & Plutzer, 2011). Occasionally, psychology courses will include a short "evolutionary psychology" unit, but, again, this inclusion is largely reduced to one or two classes primarily focused on evolved sex differences and "the mating mind." With this limited exposure, students are not taught to understand evolutionary theory as a toolkit that can help them understand diverse concepts and develop well-reasoned conclusions in their biology classes, let alone the more-broad applications characteristic of the EvoS Effect.

And, even when courses do attempt to feature evolution, human-related applications are limited, if not absent, in traditional evolution education. In this study, we have demonstrated that the greatest benefit from the EvoS Effect comes from improving students' thinking about humans. Without intentional instruction, this is severely limited in the traditional methods of teaching evolution. Students tend not to transfer the knowledge to the human-related subjects on their own; it must be part of their education.

In its current form at Binghamton University, Evolution for Everyone represents a successful experiment in evolution education, one that attempts to engage students of all academic and personal backgrounds in evolutionary studies. Focusing on human affairs and an interactive approach, the material is accessible and intriguing to students of all academic and personal backgrounds. We hope to export the course in an effort to replicate not so much its curriculum but its ideals: to enhance the teaching of science education, particularly evolution education, and to give all undergraduates the skills necessary to ask questions about their world and answer them effectively.

While increasing the emphasis on developing higher-order cognitive skills in all subjects is a widely recognized goal in education, this study focused on science education because changing the way we do science education can drive reform across all of education. Science education is inquiry-based; is hands-on; is engaging; and it changes the way students and teachers interact. It changes how we think about education.

Placing evolutionary science at the center of this reform can provide a means for not only improving student performance but also for improving the performance of teachers, administrators, and policy-makers. Evolutionary science can provide a general theoretical framework for understanding the complex interactions within the educational theatre and can inform the design of curriculum-instruction-assessment strategies, educational environments, and educational policies to best promote learning.

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Table 1. ***Demographic Information of Study Population.***

Demographic Variables	Number	Percentage
Gender		
Male	44	40.7
Female	64	59.3
Class Level		
Freshman	42	38.9
Sophomore	20	18.5
Junior	27	25.0
Senior	18	16.7
Graduate Student	1	0.9
Major		
Accounting	3	2.8
Anthropology[1]	5	4.6
Art	1	0.9
Biochemistry	2	1.9
Bioengineering	2	1.9
Biology	11	10.2
Chemistry	2	1.9
Communications	1	0.9
Computer Science	2	1.9
Education	2	1.9
Engineering	7	6.5
English	2	1.9
Environmental Studies	1	0.9
Geology	1	0.9
Human Development	3	2.8
Integrative Neuroscience	7	6.5
Mathematics[1]	3	2.8
Nursing	1	0.9
Philosophy	2	1.9
Political Science	1	0.9

Psychology	29	26.9
Undeclared	15	13.9
Religion		
Agnostic	19	17.6
Atheist	11	10.2
Buddhist	2	1.9
Christian	42	38.9
Jewish	15	13.9
Spiritual but not religious	14	13.0
Other/Undeclared	5	4.6
Youth Exposure to Evolution[2]	2.34 (0.66)	

[1] – One student was pursuing a dual major and was included in frequency count for both Anthropology and Mathematics.

[2] – Demographic variable from EALS scale. Students evaluated a series of questions related to youth exposure to evolution on a scale from 1 to 7; class mean (standard deviation) is reported.

Table 2. ***Critical Thinking Questions and Krippendorf's Alpha Scores of Inter-Rater Reliability*.**

Time	Doma	Name	Question	Approa	Logi	Eviden	Conclusi	Su
Time 1	Bio	Carnivo res	An ecologist surveying mammal populations in tropical forests observed a greater diversity of carnivores on plots of land with greater plant diversity than those with fewer plant varieties. What	0.780	0.8 43	0.799	0.871	0.90 3
		Vampir e Bats	Vampire bats drink blood from large mammals such as livestock. They will starve if they don't have a meal within three days. In addition to feeding directly from mammals, they can also regurgitate food to each other. You are studying the social behavior of vampire bats. What	0.879	0.9 11	0.616	0.954	0.96 4
		Island Ferns	A habitat conservancy group became alarmed when it performed a survey within a group of islands and found only four species of fern on a small island, compared to 16 species of fern typically	0.831	0.8 94	0.699	0.887	0.94 5
	SS	Cindere lla	Versions of the Cinderella story are found in many different cultures all around the world. As is the plight of Cinderella in her story, sociological research has revealed that step-children are much more likely to be abused by a guardian than are that parent's own children. Identify some reasons that someone may mistreat their	0.779	0.8 10	0.791	0.813	0.90 3
		Newspa per	You read a newspaper article reporting that the rate of homicide is lower in regions that have higher life	0.816	0.8 32	0.205	0.842	0.91 9
		Obesity	Many health problems, such as heart disease, cancer, and obesity, are caused by the way we eat. Please explain why is	0.766	0.7 44	0.731	0.442	0.87 0

Table 2 (Continued).

Time	Doma	Name	Question	Approa	Logi	Eviden	Conclusi	Su
		Carnivo res	An ecologist surveying mammal populations in tropical forests observed a greater diversity of carnivores on plots of land with greater plant diversity than those with fewer plant varieties. What	0.949	0.8 77	0.866	0.835	0.93 6

Time 2	Bio	Guppies	You are observing guppies in a stream. You notice that guppy school size varies according to the other fish species found in the pool and that school size is largest when an unknown orange-colored fish species is also present. When you research the unknown species, do you	0.780	0.843	0.799	0.871	0.903
		Slime Molds	Many organisms, such as aphids, slime molds, and sea anemones, reproduce sexually as well as asexually. Which mode of reproduction do you expect to find occurring during periods of favorable	0.975	0.963	0.856	0.961	0.986
	SS	Women	Women with higher occupational status and prestige tend to have fewer children than do women with lower occupational status and prestige. Explain why this may	0.952	0.953	0.931	0.948	0.983
		Cleaning	As a widespread fear of disease and illness sweeps through our world, more and more cleaning supplies are being pushed onto store shelves and sold. Please explain how and why this increase	0.883	0.943	0.888	0.945	0.968
		Guns & Snakes	About 10,000 people are killed with guns in the US annually, while spiders and snakes kill only a handful. Yet, many people tend to fear spiders and snakes about as easily as they do a pointed gun,	0.954	0.937	0.837	0.937	0.977

Table 3. ***EALS Scores (and Standard Deviations) and Results of Paired Samples t-tests between EALS Scores at Times 1 & 2, with Cohen's d Effect Sizes.***

Scale	Time 1	Time 2	t-value	Cohen's d
Evolutionary Knowledge[1]	5.09 (0.82)	5.27 (0.97)	1.930	0.19
Relevance of Evolutionary Theory[2]	5.39 (1.01)	5.70 (1.11)	3.119***	0.30
Evolutionary Misconceptions[1]	3.91 (0.95)	3.66 (0.96)	- 2.492*	- 0.24
Self Exposure to Evolution[2]	2.17 (0.74)	2.53 (0.82)	5.020***	0.49
Moral Objections[2]	2.04 (0.95)	1.91 (0.92)	-1.515	- 0.15
Social Objections[2]	3.07 (1.15)	2.79 (1.18)	-2.627**	- 0.25
Intelligent Design Fallacies[1]	2.80 (0.97)	2.59 (1.05)	-3.002***	- 0.29
Young Earth Creationist Beliefs[2]	2.42 (1.04)	2.27 (1.15)	-1.672	- 0.16
Knowledge of the Scientific Enterprise[1]	5.47 (0.97)	5.52 (1.09)	0.489	0.05
Distrust of Science[2]	2.96 (0.88)	2.62 (0.97)	-4.080***	- 0.39
Genetic Literacy[2]	5.12 (0.73)	5.31 (0.93)	2.269*	0.22
Political Activity[2]	2.55 (1.18)	2.59 (1.24)	0.351	0.03
Religious Activity[3]	3.16 (1.68)	3.25 (1.63)	1.236	0.12
Conservative Self-Identity[2]	3.47 (1.40)	3.70 (1.41)	2.327*	0.22
Attitudes Towards Life[2]	3.92 (1.48)	3.84 (1.59)	- 0.698	- 0.07

* - $p < .025$; ** - $p < .01$; *** - $p < .005$

[1] - df = 105; [2] - df = 106; [3] - df = 107

Table 4. ***LIWC Means (Standard Deviations) and Results of Independent Samples t-test, with Cohen's d Effect Sizes.***

Lexical Dimension	Time 1	Time 2	t-value	Cohen's d
Cognitive Mechanisms	16.84 (6.57)	17.51 (8.62)	1.541	0.09
Insight	2.03 (2.86)	1.39 (2.49)	- 4.184***	- 0.24
Causation	3.04 (3.00)	4.63 (4.87)	6.888***	0.39
Discrepancy	2.79 (3.25)	2.38 (3.85)	- 2.007*	- 0.11
Tentative	4.06 (3.68)	2.88 (3.61)	- 5.655***	- 0.32
Certainty	0.70 (1.34)	0.46 (1.53)	- 2.833**	- 0.16
Inhibition	0.40 (1.11)	0.78 (2.42)	3.513***	0.20
Inclusive	3.49 (3.20)	4.30 (4.65)	3.550	0.20
Exclusive	2.40 (2.98)	2.19 (3.13)	- 1.180	- 0.07

* - p < .05, ** - p = .005, *** - p < .001

Note: DF = 1223

Table 5. ***Scores (Stand Deviations) and Results of Paired Samples t-tests for Critical Thinking Questions at Times 1 and 2.***

Question Set	CT Component	Time 1	Time 2	t-value	Cohen's d
Carnivores[1]	Approach	2.20 (0.41)	2.49 (0.61)	4.753***	0.48
	Logic	2.14 (0.52)	2.20 (0.57)	0.954	0.10
	Evidence	0.02 (0.17)	0.16 (0.45)	2.762**	0.28
	Conclusion	1.98 (0.58)	2.06 (0.51)	1.356	0.14
	Sum	6.33 (1.36)	6.90 (1.84)	3.220**	0.33
Bio[2]	Approach	2.08 (0.38)	2.21 (0.26)	3.233**	0.32
	Logic	2.01 (0.43)	2.05 (0.36)	0.967	0.09
	Evidence	0.04 (0.14)	0.06 (0.16)	1.324	0.13
	Conclusion	1.91 (0.36)	1.82 (0.35)	- 2.018*	- 0.20
	Sum	6.03 (1.12)	6.14 (0.96)	0.993	0.10
SS[3]	Approach	2.09 (0.37)	2.33 (0.41)	5.589***	0.54
	Logic	1.94 (0.38)	2.08 (0.43)	3.074**	0.30
	Evidence	0.26 (0.42)	0.26 (0.40)	0.107	0.01
	Conclusion	1.70 (0.30)	2.07 (0.40)	10.098***	0.97
	Sum	5.99 (1.20)	6.74 (1.46)	5.432***	0.52
Combined[3]	Approach	2.05 (0.29)	2.12 (0.35)	1.909	0.18
	Logic	1.95 (0.35)	2.05 (0.42)	2.409*	0.23
	Evidence	0.07 (0.26)	0.10 (0.30)	0.831	0.08
	Conclusion	1.85 (0.38)	1.95 (0.35)	2.589**	0.25
	Sum	5.94 (1.09)	6.34 (1.17)	3.672***	0.35

Notes: Questions were analyzed by type (single question measure—Carnivores, Bio, SS) and for the combined values. Cohen's *d* effect sizes were calculated for each.

* - p < .05, ** - p < .015, *** - p < .001

[1] - df = 96; [2] - df = 105; [3] - df = 107

Table 6. ***Scores (and Standard Deviations), and Results of Paired samples t-tests for Domain Transfer of Knowledge, with Cohen's d Effect Sizes.***

Question Set	Time 1	Time 2	t-value	Cohen's d
Carnivores[1]	0.08 (0.28)	0.07 (0.26)	- 0.241	- 0.02
Bio[2]	0.30 (0.52)	0.51 (0.63)	2.859*	0.28
SS[2]	0.13 (0.39)	0.43 (0.69)	4.573**	0.44
Combined[2]	0.43 (0.66)	0.94 (1.10)	4.783**	0.46

* - p = .005, ** - p < .001

[1] - df = 96

[2] - df = 107

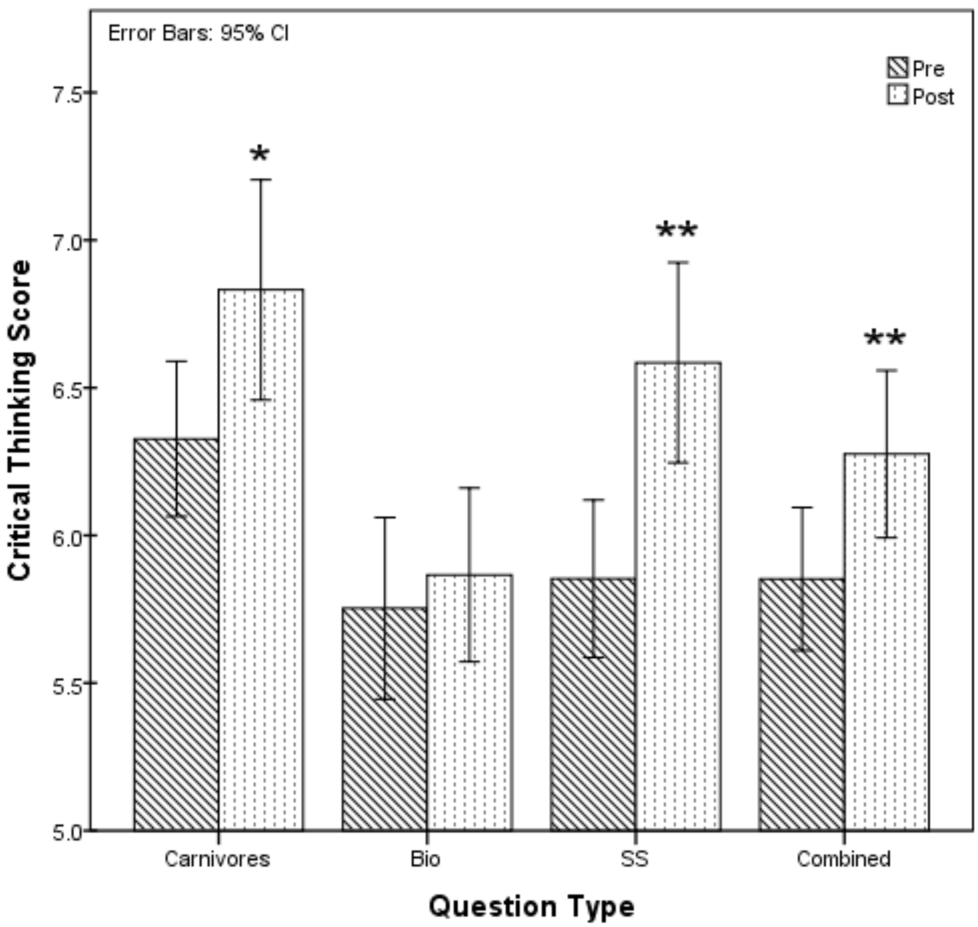
Figure 1. Critical thinking/problem solving rubric.

Figure 2. Critical thinking scores (*Sums*) at times 1 and 2 for each question type and for the combined set. * indicates $p < .015$; ** indicates $p < .001$

Figure 3. Scores of critical thinking components for *Bio* and *SS* questions. Results indicate that students demonstrated the greatest improvements of CT in the *SS* questions. This pattern suggests that, while students may have already been in the practice of incorporating evolutionary reasoning into biological topics, evolutionary theory provided them with a new framework for thinking about human-related subjects and allowed them to better rationalize in these domains. * indicates $p < .05$; ** indicates $p < .015$; *** indicates $p < .001$.

Figure 4. Transfer scores at times 1 and 2 in *Bio* and *SS* responses. Results indicate that students were more likely to incorporate evolutionary reasoning at Time 1 into responses for biological questions than for the human-related topics. This bias was removed at Time 2, where students were equally as likely to incorporate evolution into their responses from either domain (*Bio* or *SS*). For both domains, students were more likely to incorporate evolutionary thinking at Time 2. * indicates $p < .010$; ** indicates $p = .005$; *** indicates $p < .001$.

	0	Benchmark 1	Milestones 2	3	Capstone 4
Approach/Propose Solution	Does not meet benchmark -or- attempt to answer question.	Propose a solution that is vague, simplistic, or cliché.	Two or more solutions that may be vague, simplistic or cliché. -or- One solution that represents a basic understanding.	Proposes one or more solutions from the same point of view that indicate a deep comprehension of the problem. -or- Poorly presents multiple points of view.	Proposes multiple points of view that indicate a deep comprehension.
Development of Argument/Logical Support	Does not meet benchmark -or- attempt to answer question.	Provides limited logic that is too general to explain the specific details of the problem.	Has specific support for argument but requires reader to make assumptions.	Argument uses adequate reasoning and support for assertions.	Uses a clear and concise argument using a *systematic* flow of logical support based off the premise.
Evidence/Examples	Does not meet benchmark -or- attempt to answer question.	Example is too vague or general.	Uses one or more clear examples but is limited to the scope of the information given.	Brings in specific, outside, relevant information that is not well-integrated into response; still leaves something out.	Brings in outside, relevant information to create a scenario that is easily envisioned by the reader, that addresses every proposed solution.
Conclusion	Does not meet benchmark -or- attempt to answer question.	Conclusion is ambiguous or illogical to the premise. (Doesn't make sense.)	States a general conclusion that, because it is so general, also applies beyond the scope of the inquiry findings.	States a specific conclusion that is drawn from information used but: does not address all proposed solutions, –or– does not have systematic flow.	Clearly states a conclusion that *systematically* flows from information used. Conclusion will leave no ambiguities to the position; they have addressed every proposed solution.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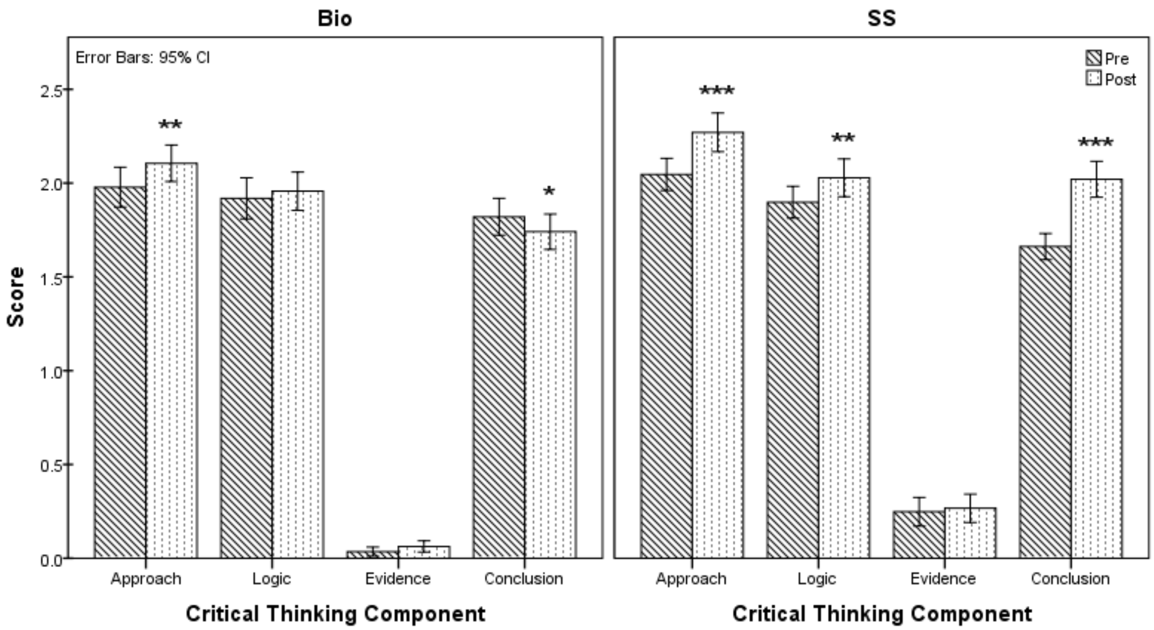
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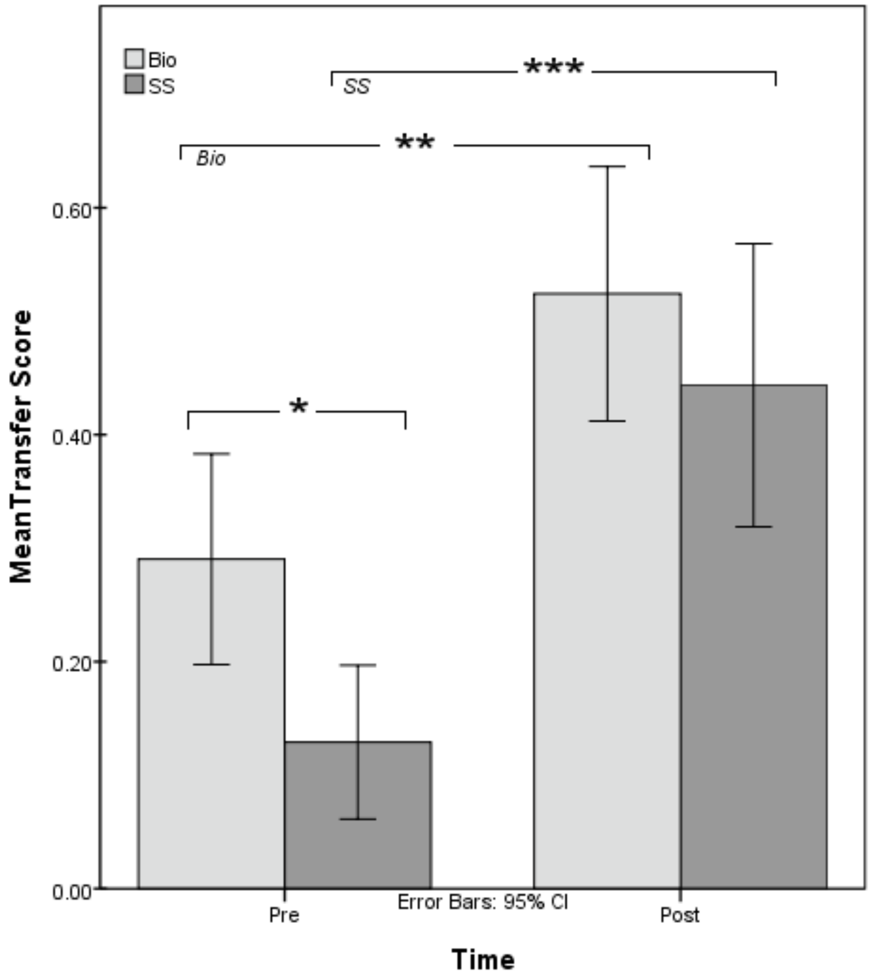
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Appendix

Questions and Cronbach's Alphas for All Scales in the Evolution Literacy Survey for Times 1 and 2, administered at the Beginning and End of the Course.

Questions	Number of Items	Time 1	Time 2
Evolutionary Knowledge	N = 8	0.670	0.813
In most populations, more offspring are born than can survive.			
Individuals don't evolve, species do.			
Mutations can be passed down to the next generation.			
Increased genetic variability makes a population more resistant to extinction.			
The more recently species share a common ancestor, the more closely related they are.			
Natural selection is the only cause of evolution.[1]			
Mutations occur all the time.			
Individuals better suited to their environment are more likely to survive and reproduce.			
Relevance of Evolutionary Theory	N = 9	0.896	0.928
The theory of evolution helps us understand plants.			
Evolutionary theory is highly relevant for biology.			
The theory of evolution helps us understand animals.			
The theory of evolution helps us understand human origins.			
For explaining human behavior, evolutionary theory is irrelevant.[1]			
Evolutionary theory is highly relevant for the social sciences (e.g., anthropology, psychology, sociology).			
Evolutionary theory is highly relevant for the humanities (e.g., history, literature, philosophy).			
Evolutionary theory is relevant to our everyday lives.			
The theory of evolution helps explain the world as it is in the present.			
Evolutionary Misconceptions	N = 6	0.627	0.587
Natural selection is a random process.			
Natural selection is synonymous (means the same) as evolution.			
Characteristics acquired during the lifetime of an organism are passed down to that individual's offspring.			

Species evolve to be perfectly adapted to their environments.			
Evolution means progression towards perfection.			
Evolution is a linear progression from primitive to advanced species.			
Self Exposure to Evolution	N = 5	0.822	0.805
I’ve visited evolution related web sites (e.g., Science Daily, Pharyngula, Edge.org).			
I’ve watched evolution related videos on the web (e.g., Ted.com, YouTube).			
I read science magazines featuring evolution (e.g., Discover, National Geographic, Nature).			
I’ve watched nature shows that discussed evolution (e.g., PBS/ Nova, Discovery, National Geographic).			
I’ve read evolution related books (e.g., by Richard Dawkins, E.O. Wilson, Steven Pinker).			
Moral Objections	N = 5	0.594	0.525
People who accept evolution do not believe in God.			
People who accept evolution as fact are immoral.			
If you accept evolution, you really can’t believe in God.			
Darwinism strips meaning from our lives.			
People can be moral and believe in evolution at the same time.[1]			
Social Objections	N = 6	0.833	0.812
The theory of evolution has contributed to racism.			
Applying the theory of evolution to human affairs implies we are not fully in control of our behavior.			
The theory of evolution has contributed to sexism.			
The theory of evolution has contributed to an increase in abortion.			
The theory of evolution has contributed to genocide (the deliberate killing of a group based on nationality, race, politics, or culture).			
The theory of evolution has contributed to an increase in euthanasia (the act of killing someone painlessly or allowing to die to stop the suffering; also called mercy killing).			
Intelligent Design Fallacies	N = 11	0.809	0.809
There is scientific evidence that humans were created by a supreme being or intelligent designer.			

There is no evidence that humans evolved from other animals.			
The theory of evolution is a matter of faith and belief, just like religion.			
Humans were specially designed.			
There are no transitional fossils (remains of life forms that illustrate an evolutionary transition).			
It is statistically impossible that life arose by chance.			
The theory of evolution does not explain similarities or differences between chimps and humans.			
Complex biological systems cannot come about by slight successive modifications (i.e., they are irreducibly complex).			
Evolution is a theory in crisis.			
Evolution violates the 2nd law of thermodynamics (that systems move toward disorder, not order).[2]			
Natural selection cannot create complex structures; it is like a tornado blowing through a junkyard and creating a 747.			
Young Earth Creationist Beliefs	N = 9	0.868	0.898
I read the bible literally.			
God created humans in their present form.			
Humans never could have been related to apes.			
The Earth isn't old enough for evolution to have taken place.			
There was a time when humans and dinosaurs lived on earth together.			
Present animal diversity can be explained by the Great Flood.			
Young Earth Creationist Beliefs (Continued)			
A majority of present-day geological features are the result of the Great Flood.			
Adam and Eve of Genesis are our universal ancestors of the entire human race.			
All modern species of land vertebrates are descended from those original animals on the ark.			
Knowledge About the Scientific Enterprise	N = 6	0.753	0.802
Good theories can be proven by a single experiment.[1]			
For scientific evidence to be deemed adequate, it must be reproducible by others.			
Scientific ideas can be tested and supported by feelings and beliefs.[1]			
Scientific explanations can be supernatural.[1]			

Theories requiring more untested assumptions are generally better than theories with fewer assumptions.[1]			
Good theories give rise to testable predictions.			
Distrust of the Scientific Enterprise	N = 7	0.522	0.570
Contemporary methods of determining the age of fossils and rocks are untrustworthy.[2]			
The data used to support evolution is untrustworthy.			
The theory of evolution is capable of explaining the diversity of life.[1]			
Evolutionary theorists believe that if something is natural then it is good or right.			
Evolutionary theorists believe that inevitable inequality is morally acceptable.[3]			
Evolutionary theorists believe that because the strongest survive, it's a mistake to help the weak.[3]			
The available data are ambiguous as to whether evolution actually occurs.[4]			
Genetic Literacy	N = 9	0.642	0.765
Humans share a majority of their genes with chimpanzees.[5]			
Humans share more than half of their genes with mice.[5]			
Ordinary tomatoes do not have genes, whereas genetically modified tomatoes do.[1,5]			
Today it is not possible to transfer genes from one species of animal to another.[5]			
All plants and animals have DNA.[5]			
Humans have somewhat less than half of the DNA in common with chimpanzees.[1,5]			
You can see traces of our evolutionary past in human embryos.			
Humans developed from earlier life forms.			
Mutations are never beneficial.[1]			
Political Activity	N = 6	0.900	0.934
To what degree are you political?			
To what degree are you politically active?			
To what degree are you politically aware/up-to-date?			

To what degree do your political views influence your daily life?			
To what degree do your political views influence your decisions?			
To what degree do your political views influence courses you enroll in?			
Religious Activity	N = 6	0.948	0.935
To what degree are you religious?			
To what degree does religion impact your daily life?			
To what degree does your religion influence your decisions?			
To what degree do you participate in religious activities?			
How much do you believe in God?			
Religion is especially important to me because it answers many of my questions about the meaning of life.[6]			
Conservative Self-Identity	N = 5	0.790	0.786
To what degree are you conservative?			
In general, how do you self-identify politically?[7]			
In general how liberal/conservative are you on social issues (abortion, same-sex marriage, flag burning, etc.)?[8]			
In general how liberal/conservative are you on economic issues (welfare, taxation, free market policies, etc.)?[8]			
In general how liberal/conservative are you on foreign policy and defense issues (defense spending, combating terrorism, pre-emptive war)?[8]			
Attitudes Toward Life[5]	N = 3	0.693	0.773
Life begins at conception.			
After conception, a developing human is only a cluster of cells, and it makes no sense to discuss its moral condition.[1]			
All stages of human life—embryo, fetus, child, adult—should have the same legal protections.			

Notes: Cronbach's alphas are a measurement of the inter-correlation of all items in a scale (measured on a 0–1 scale).

1 – Items are reverse coded (i.e., 1→7, 2→6, etc.) in order to maintain positive correlations between all scale items

2 – See also Ingram and Nelson (2006)

3 – Item was drawn from R. Deaner (personal communication with P. Hawley, January 20, 2009, as reported in Hawley, Short, McCune, Osman, and Little, (2011))

4 – See also Rutledge and Sadler (2007)

[5] – From Miller, Scott, and Okamoto (2006)

[6] – See also Dudley and Cruise (1990)

[7] – From ANES, 2009

[8] – From Carney, Jost, Gosling, and Potter (2008)