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Pedagogical Approaches and Instructional Content that Predict Increased Acceptance of Biological Evolution in University Students

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A dissertation submitted to the faculty of
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Doctor of Philosophy

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ABSTRACT

Pedagogical Approaches and Instructional Content that Predict Increased Acceptance of Biological Evolution in University Students

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Evolution is the central organizing theory of biology. Without evolutionary theory, biology becomes a somewhat tangential assemblage of facts about living organisms, which is precisely how it is viewed by many students. Many teachers teach evolution in a limited capacity or avoid it entirely due to fear of opposition, lack of confidence in their own understanding, or lack of acceptance of the theory themselves. When evolution is not taught, or is not accepted, it cannot be utilized to make sense of the field, and is quickly forgotten by students. While some studies have shown a correlation between instruction about evolution and acceptance of evolution, many have not. Understanding which instructional factors, both pedagogical and conceptual, contribute to increases in evolution acceptance are paramount if we are going to make biology education more cohesive and applicable beyond the context of the course itself.

To better understand what these factors may be, I utilized curriculum that I developed previously to teach introductory biology to non-biology majors that incorporated evolution as the organizing structure and appeared to produce considerable increases in acceptance of evolution based on the lack of hostility and pushback from the students in the course. I verified that the curriculum as taught produced increases in acceptance of evolution using the Measure of Acceptance of the Theory of Evolution (MATE) instrument as a measure of acceptance, and by asking students on the final exam what their position had been before instruction and if it had changed as a result of the course. Both measures revealed a considerable increase in evolution acceptance. Using a full factorial experimental design, tested three major pedagogical approaches that have all been hypothesized to contribute to increasing evolution acceptance: Constructivist-inspired vs Behaviorist-inspired, active vs less active instruction, and reflexive journaling vs not journaling. While all possible combinations of treatments showed statistically significant increases in evolution acceptance, there was no statistically significant difference between any of the treatments or combinations of treatments. Also, using Thematic Analysis, we coded and analyzed the responses that students provided as to the concepts from class that played a role in their having changed or not changed their positions on evolution as reported on the final exams, and in their reflexive journals which provided a valuable window into the concepts that we might emphasize or choose to remove or deemphasize in the future to maximize the probability that student acceptance of evolution will increase following instruction.

Keywords: constructivism, behaviorism, active learning, reflexive journaling, pedagogy, evolution acceptance, thematic analysis

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Chapter 1

Why teach biology if it is rejected? How to teach evolution so that it can be accepted

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Abstract

There exists a disconnect between instruction about biological evolution and acceptance of evolution by students. This disconnect prevents students from applying the theory to their lives or to their understanding of the field of biology. We examine the literature for common barriers to the acceptance of evolution, correlates with acceptance of evolution, and potential means by which education might result in increased levels of acceptance among students. We find that by changing the way that teachers themselves are taught, and by altering the methods teachers use to teach, it is likely that student acceptance of evolution can increase from instruction.

Introduction

Biological evolution is the central organizing theory of the field of biology (Dobzhansky 1973; American Association for the Advancement of Science (AAAS) 1993 2011; Bybee 1997; Kagan 1992; National Association of Biology Teachers (NABT) 2010; National Research Council (NRC) 1996). Without evolutionary theory, biology is reduced to an assemblage of tangential and loosely connected facts. Despite possessing a unifying theory, biology as a subject is still frequently viewed by students as being a disparate and nonsensical field requiring extensive levels of memorization of seemingly unrelated topics (Nomme 2014). Given this perceived disconnect between topics, every aspect of biology becomes more difficult or even impossible to understand and is therefore avoided by many students (Nomme 2014).

A major factor contributing to the dissociation of concepts in biology is the fact that the unifying element (evolutionary theory) is so widely rejected. Nearly a third of American adults firmly reject evolution (Miller et al. 2006), and less than a quarter accept evolution of humans (Lovely and Kondrick 2008). Among educators, evolution is occasionally rejected and frequently ignored or marginalized as to evade what is perceived as avoidable conflict with both students and parents (Lerner 2000; Farber 2003; Olivera et al. 2011; Verhey 2005; Goldston & Kyzer 2009). This widespread rejection within the general populous comes despite near complete consensus among scientists (Pew Research Center 2015; Alters and Alters 2001). If the central organizing theory of the entire field of biology is rejected, then there is some question as to the utility of attempting its instruction at all. If what is taught isn't internalized, then it becomes nothing more than trivia. Biology is generally considered a part of a general education at all levels, yet students that do not receive instruction about or that do not accept evolution are less likely to retain the information (Nehm & Schonfeld 2007) or transfer their understanding to applications outside of the course itself (Nehm & Reilly 2007; Catley & Novack 2009; Fowler & Zeidler 2016).

Instruction does not mean acceptance

Understanding that evolution is almost universally accepted by scientists, one might postulate that rejection of evolutionary theory is related to general ignorance of the subject matter. This might seem particularly plausible given that most students are unable to properly articulate what evolutionary theory posits (Robbins & Roy 2007), and there is a correlation between knowledge of evolution and acceptance (Weisberg et al. 2018). As knowledge of evolution generally increases with instruction (Kim & Nehm 2011; Moore et al; 2011) it has been frequently hypothesized that acceptance of evolution should be positively correlated with instruction and knowledge of evolution, especially natural selection (Anderson et al. 2002; Bishop and Anderson 1990; Demastes et al. 1995; Lord and Marino 1993; Nehm and Schonfeld 2008; Sinatra et al. 2003). However, these studies have revealed no such correlation. For example, Sinatra et al. (2003) found that after instruction about photosynthesis, evolution of animals, and human evolution that students' acceptance of photosynthesis, the non-controversial control, went up significantly, but there was no such increase in acceptance for either animal nor human evolution following similar instruction on these topics. Though some studies have shown an increase in acceptance with instruction (Weisberg et al. 2018; Robbins and Roy 2007), particularly outside of the United States (Akyol et al. 2010; Kim and Nehm 2011; Ha et al. 2012), it more often seems to be an effective means of temporarily increasing knowledge of evolution, but not acceptance (Bishop and Anderson 1990; Demastes et al. 1995; Jensen and Finley 1996; Sinatra et al. 2003; Asterhan and Schwarz 2007; Stover and Mabry 2007; Rutledge

& Sadler 2011; Deniz & Donnely 2011; Lawson and Worsnop 1992; Crawford et al. 2005; Cavallo & McCall 2008). Thus, the correlation between understanding and acceptance likely indicates that acceptance is a predictor of understanding and not the other way around (Smith & Siegel 1994).

If biology is going to remain a meaningful part of a general education, then it stands to reason that we need to teach it in such a way that promotes retention of the material and the application thereof by the students to the real world. If students are going to accomplish these goals, then we need to teach it in such a way that they can accept what is being taught. As acceptance is not, generally, correlated with instruction it leads to the question, what can we do to make instruction about evolution truly effective? To answer this question, we engaged in a detailed look at the literature to see what ideas have been presented and tested that might, if implemented in classrooms, increase the efficacy of biology teaching by increasing acceptance of biological evolution.

The correlates of acceptance

Many factors such as per capita gross domestic product (Heddy & Nadelson 2012), parents' education level (Deniz et al. 2008), conservative political orientations (Nadelson & Hardy 2015), and feeling of certainty (Ha et al. 2012), have been shown to be correlated with acceptance of evolution. Some of the most frequently observed correlates are religiosity and basic science literacy (Heddy & Nadelson 2012; Glaze et al. 2015), particularly with understanding of evolution and of the nature of science (Cofré et al. 2018; Dunk et al. 2017; Lombrozo et al. 2008; Trani 2004; Glaze et al. 2015; Cavallo et al. 2011; Carter & Wiles 2014; Weisberg et al. 2018). Generally, religiosity is found to have a negative correlation with acceptance of evolution in that the more religious an individual is, the less likely they are to accept evolution (Heddy & Nadelson 2012; Glaze et al. 2015). Conversely, correct understanding of the nature of science and of evolutionary theory are positively correlated with acceptance (Lombrozo et al. 2008; Trani 2004; Glaze et al. 2015; Cavallo et al. 2011; Weisberg et al. 2018). As stated previously, knowledge of evolution is not always found to be correlated with acceptance. When knowledge and acceptance are correlated, it sometimes only makes a difference in students that were undecided on the subject before instruction (Wilson 2005; Ingram & Nelson 2006). It could be that knowledge and understanding are not always synonymous because constructing such an understanding can be impeded by misconceptions both present in students and taught by instructors (Blackwell et al. 2003; Sinatra et al. 2008; Yates & Marek 2014). Assuming a causative relationship between these correlates and acceptance, one could conceivably increase acceptance of evolution by doing any of the following: increasing students' understanding of the nature of science, increasing students' correct understanding of evolutionary theory particularly of "macroevolution", or the idea that the small-scale "micro" evolutionary steps can accumulate and lead to speciation (Nadelson & Southerland 2010), or by decreasing students' religious conviction.

Reduce religiosity

Considering the negative correlation between religiosity and acceptance of evolution, many teachers and popularizers of science have attempted to confront the apparent incompatibility of science and religion by attempting to discredit the religious beliefs of the students (Dawkins 2016; Mahner & Bunge 1996). While this may be effective for some, it is also likely that it simply reinforces the belief that science and religion are incompatible and therefore hinders acceptance in those who are unconvinced that they should abandon their religious beliefs. In addition, promoting an accurate understanding of students' religious doctrine and discussing ways in which science and religion can be reconciled can lead to higher levels of acceptance of evolution even among highly religious students (Brickhouse et al. 2000; Manwaring et al. 2015; Barnes et al. 2017). Winslow et al. (2011) found that among Christian students raised as creationists, acceptance was possible when students were presented with evidence, when they were encouraged to examine the literalness of the scriptural accounts of creation, when evolution was presented as something unrelated to their eternal salvation, and when their professor was viewed as a religious role model who accepted evolution. Holt et al. (2018) found that "The single factor linked with the reduction in both creationist reasoning and in students' perceived conflict between evolution and their worldview through a semester was the presence of a role model."

Along those lines, it is essential to differentiate between accepting and believing in evolution as belief and acceptance are not, necessarily, synonymous (Smith & Siegel 2004). Evolution is not a belief system, but a rational explanation for a host of facts which, to date, cannot otherwise be explained. One therefore does not believe in evolution, but accepts it as the most reasonable explanation we have given the facts. This understanding is likely associated with understanding of the nature of science and its limitations, and if understood could mitigate the belief that accepting evolution threatens ones' eternal salvation (Winslow et al. 2011).

All of this would suggest that, for highly religious students, the best way to promote acceptance might not be to attack their beliefs, but to aid them in reconciling their beliefs with science and serving as a non-hostile role model. In the case that the instructor holds uninformed or antagonistic viewpoints towards religion this approach should only be implemented with great care (Brickhouse et al. 2000). Regardless, presenting science as an antithesis to religion may do more to promote rejection than acceptance. Whether it is effective or not to diminish the religious beliefs of students, Rice et al. (2015) found that, for university faculty, knowledge and acceptance of evolution were positively correlated, even in faculty with creationist viewpoints, suggesting that acceptance and knowledge can increase conjointly irrespective of the religious position of the learners. Attacking the students' religious convictions is likely not the best way to increase the likelihood of accepting evolution.

Reduce misconceptions

Given the variation in the strength of students' religious beliefs as well as the compatibility of those beliefs with evolutionary theory, in many instances it may be counter-productive to engage those convictions directly or indirectly. Attempting to increase acceptance of evolution by confronting student religiosity may not always be an effective option for instructors. One of the principle issues related to religion and science is that religious students may be at an increased risk of possessing misconceptions that hinder proper understanding of science generally, especially evolution (Dagher & BouJaoude 1997; Sinatra et al. 2003; Blackwell et al. 2003). To increase the likelihood of acceptance among religious students it may be effective to address those misconceptions in lieu of confronting the religion directly.

The importance of confronting misconceptions is not limited to religious students in any way, but such misconceptions permeate society irrespective of religiosity (Blackwell et al. 2003; Sinatra et al. 2008; Yates & Marek 2014). In some cases, people may claim to reject evolution based on their religious convictions, but this may not be the actual motivation. Trani (2004) found that many teachers claimed to reject evolution due to their religion, but upon further analysis it appeared to be more due to a lack of understanding of the actual theory of evolution, and a lack of understanding of the nature of science.

To confront the acceptance barrier of misconceptions one could confront those misconceptions directly in the classroom as a part of the curriculum. Misconceptions about evolution are numerous and include things such as those listed by Gregory (2009). Wilson (2005) designed an entire course with the objective of increasing interest in, knowledge and acceptance of evolution. In the course the researchers focused the beginning of the course on the implications of evolution as many of the most common reasons for dismissing the theory come from incorrect assumptions regarding its implications. Although some have chosen to devote the whole of a course to confronting such misconceptions, all biology courses are likely to benefit from taking time to assess and address the misconceptions present in the students.

What may be better than correcting misconceptions would be to begin to teach evolution explicitly as early as possible to students so that they can develop accurate initial conceptions regarding evolution and the nature of science before they have the opportunity to construct inaccurate ones (Weiss & Dreesmann 2014). Kelemen et al. (2014) found that children from 5 to 8 years of age can be taught basic natural selection using a picture-storybook, and retain and apply that information even several months after instruction. Contrary to what many might think, correct understanding of evolution does not seem to be outside of the reasoning ability of even very young students.

Capability of teachers

Among the major considerations which may prevent earlier implementation of evolution into curricula is the understanding of the teacher. Being that we are seeking to evade misconceptions among learners, it is important to consider that many teachers of younger students themselves possess these misconceptions (Blackwell et al. 2003; Yates & Marek 2014). Elementary teachers, for example, may have a single semester or less of biology education before beginning teaching, a single course which may or may not have taught accurate principles of biological evolution. Teachers are often not sufficiently knowledgeable to correctly teach these concepts and may deliberately or inadvertently teach misconceptions explicitly in the classroom. Even among more highly trained biology-specific teachers, such misconceptions are prevalent. Many either teach these misconceptions, or use them, combined with concerns of parent outrage, as an excuse to avoid the topic altogether. Rutledge & Mitchell (2002) found that 43% of surveyed teachers completely avoided, or only briefly mentioned evolution in Indiana biology classrooms. The principle reasons that the topic was avoided was that the teachers felt ill-equipped in terms of their personal understanding, or rejected it themselves. Some teachers do not want to teach evolution, others are incapable (Wiles & Branch 2008). Though beginning evolution education at an earlier age may increase the likelihood of acceptance, it is unlikely that our current workforce of teachers is adequately trained to do so.

If we are to have teachers that are more equipped to teach evolution in schools then we need a better way to teach not only our students, but our teachers (Weiss & Dreesmann 2014; Blackwell et al. 2003). Rutledge & Warder (2000) found that Indiana public high school biology teachers were ill-prepared by their academic qualifications to teach evolution, or the nature of science and that most college and university biology departments do not require evolution or nature of science coursework to obtain teacher certification in biology. Even when attempts are made to design courses to increase instructor knowledge of evolution these courses are frequently ineffective at changing the way that instructors teach. For example, a course taught at the graduate-level to instructors designed to increase instructor knowledge and reduce misconceptions was effective at increasing knowledge and reducing misconceptions, but did not reduce the desire of instructors to teach anti-evolutionary ideas (Nehm & Schonfeld 2007) suggesting that it did not have an impact on instructor acceptance.

For students and educators that have received quality instruction, but especially for those whose early-life evolution education has left them either uninformed or misinformed about evolution, the question then becomes how do we teach evolution so that they will be most able to understand and accept it?

Constructivism

Alters & Nelson (2002) suggested teaching using constructivism as a means of increasing the efficacy of evolution teaching. Constructivism, when applied not only as a theory of learning but as a theory of education, should promote conceptual change in learners because it, unlike many other educational theories such as behaviorism, is not capable of ignoring the misconceptions and past experiences of the students. With behaviorism, instructors may elicit desired responses from learners with sustained reinforcement of those behavioral responses. However, the knowledge that they are to attain is not owned by the learner, but is predetermined by the instructor. Understanding is only measured by the learner behaving in the manner desired by the instructor (such as repeating a word or phrase) in response to specific stimuli (such as a test question), which are again determined by the instructor (Scheurman 1998). Behaviorism treats learners as though they were a blank slate and does not account for the effect that their preconceived notions may have on their ability to learn new material (Ertmer & Newby 1993). Cognitivism accepts that learners may have preconceived notions that may interfere with their ability to obtain knowledge, but it still views knowledge as something created outside of the learner and therefore something inflicted upon the learner and not constructed thereby (Ertmer & Newby 1993). Constructivism is arguably a subset of cognitivism that assumes that knowledge cannot be transferred intact from one individual to another, but rather that all people construct within themselves a logical set of explanations for the experiences that they have had (Jonassen 1999). When we ignore the past experiences of a learner we are unable to predict how they will incorporate the new information being presented into their existing schemas. A constructivist classroom will raise questions and problems that require students to do things based on their prior beliefs, but that have results or answers which may not fit into their existing schemas requiring students to reexamine their existing schemas to see if they remain credible, or if they need to be replaced (Lawson 1994). In addition to confronting incorrect schemas that might otherwise go undetected, such experience may increase overall reasoning abilities, which, as suggested by Lawson & Wesner (1990), should decrease nonscientific beliefs in students. These reasons should, at least hypothetically, make constructivist teaching more effective in terms of promoting acceptance of evolution.

Active learning

Freeman et al. (2014) in a meta-analysis of 225 studies found that the use of active learning of any kind increased exam scores an average of 6% and that failure rates in STEM courses were 55% higher in non-active courses than in active courses. Active learning was also suggested as a means of increasing knowledge and acceptance of evolution specifically by Alters and Nelson (2002) because learning tends to increase in active learning classrooms. Where learning increases, instructors have a greater chance of increasing student understanding of the two key knowledge correlates with evolution acceptance: the nature of science and of evolution. Nehm & Reilly (2007), for example, found that classes taught using active learning achieved higher scores on key concepts of natural selection and had fewer misconceptions than classes taught traditionally. Active learning environments may too provide a greater opportunity for instructors to gain insight into the thoughts and misconceptions of their students and thus more able to address them deliberately in the classroom.

Reflexive journals

Reflective journals are already widely used in other fields of education such as nursing (Blake 2005; Raterink 2016; Miller 2017), counselling (Chabon & Lee-Wilkerson 2006; Hubbs & Brand 2005), and statistics (Thropp 2017). These journals proved an active-learning component to the course allowing the students to reflect on the material (Blake 2005; Thropp 2017), as well as giving instructors critical feedback into the understanding and application of the material in their students (Chabon & Lee-Wilkerson 2006). In Biology classrooms, completing journaling assignments has been correlated with an increase in understanding and acceptance of biological evolution (Scharmann & Butler 2015). While the lack of a control in this study prevents us from knowing if journaling caused any portion of the increase in acceptance that the researchers observed, as with other fields, the journals helped researchers gain a clearer view into students' thoughts. Combined with the use of active learning in the classroom, they saw an increase in acceptance of evolution over the course of the semester. Journals may, in and of themselves, increase acceptance, but at the very least journals can inform instructors about the major misconceptions and understanding of their classes so that instructors can modify their curricula accordingly.

Make evolution relevant

To most biologists the importance of evolutionary theory is obvious as it not only makes sense of the field, but gives us the ability to understand and predict many real-world, relevant phenomena such as the spread of disease, pest management, and the potential impacts of climactic change. Many students, nonetheless, never see the practicality of the theory. Learning is often impeded because students do not see the relevance of the subject to their lives (Heddy & Sinatra 2013). One of the great benefits of active learning is that it increases the attentiveness of the students (Prince 2004), but if the material is trivial and irrelevant then such benefits may be lost (Heddy & Sinatra 2013). Infanti & Wiles (2014) found that exposing students to "Evo in the News" (news articles involving evolution) was correlated with increases in student attitudes regarding evolution and its relevance. Thus, we may benefit from not only explaining the historical importance of evolution, but focusing on how evolution impacts modern life for our students. Stover et al. (2013) found that acceptance of evolution and other controversial topics in science increased when placed in a context of public health. As is often the case, science is perceived as most relevant when it is directly related to human health and survival. This would include the evolution of diseases, drug resistance, herb and pesticide resistance, communicability of diseases from other organisms, selective breeding and others. There are likely countless examples of ways that evolution impacts modern life, and the more examples we can bring to the students the more likely they are to listen to the content being shared.

Social identity theory

Social identity theory is a theory in social psychology that explains much about intergroup behavior based on their perceived membership to a relevant social group (Turner & Oakes 1986; Tajfel et al. 1979; Tajfel & Turner 1986). This theory led to the creation of self-categorization theory that describes the conditions under which an individual will identify assemblages of individuals (potentially including themselves) as being a group, and the consequences of identifying people as a group (Haslam, S. A. 1997). Based on these theories, social identities are cognitively signified as group stereotypes that both describe and assign beliefs, attitudes and behaviors that minimize differences with members of one's perceived group and maximize differences with members of other groups whether those groups were formed randomly or non-randomly (Tajfel 2010). As a result, people tend to be unreasonably critical of ideas that come from individuals outside of their perceived group, and unreasonably accepting of ideas that come from individuals within their perceived group (Tajfel 2010). While research has not focused on the impact of social identity theory and in-group formation on evolution acceptance specifically, it would explain why acceptance rates vary based on factors such as political party and religious affiliation (Nadelson & Hardy 2015). It stands to reason that students' perception of their instructor as being either part of their in-group or not part of their in-group could dramatically influence the probability of evolution acceptance among their students. This could potentially be addressed by taking steps to approximate the stereotypes of the students' in-group, or at least not deliberately portray oneself as a member of an out-group (Holt et al. 2018) and also by building a strong in-group culture in the classroom and never to isolate members of the class as being members of some other group.

Conclusions and future directions

While our understanding of the importance of accepting evolution and how to increase that acceptance is increasing, we still have much to accomplish. In many cases the implementation of this knowledge is inhibited by the fact that teachers are unable or unmotivated to make the changes necessary to improve the quality of biology education as to increase student acceptance of the fundamental theory of evolution. Despite the obstacles, there is great reason for optimism. A greater focus on student understanding of the nature of science and evolutionary theory promises to increase student acceptance particularly as these topics are presented in an active, constructivist, and relevant way. Gone are the days when we, as scientists, felt the need to engage in the battle of science versus religion to inform our students. We do not need to tear down as much as we need to confront misconceptions and build, as early as possible, correct ideas about the mechanisms and implications of evolution.

Many great ideas have been postulated regarding teaching strategies that are likely to increase acceptance. As we focus on studies that experimentally test these hypotheses we are likely to have greater and greater clarity as to the most effective ways to present science and biology to modern students. As we understand how to address controversial topics such as evolution we are likely to gain insight into how we might better inform the public about a host of other relevant and important topics that are similarly perceived as being controversial (e.g., reproductive technology, climate change). We have long been fighting this battle, but we are constantly learning which battles really should be fought.

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References

Akyol, G., Tekkaya, C., & Sungur, S. (2010). The contribution of understandings of evolutionary theory and nature of science to pre-service science teachers' acceptance of evolutionary theory. *Procedia-Social and Behavioral Sciences*, *9*, 1889-1893.

Alters, B. J., & Alters, S. (2001). *Defending evolution in the classroom: A guide to the creation/evolution controversy*. Jones & Bartlett Learning.

Alters, B. J., & Nelson, C. E. (2002). Perspective: Teaching evolution in higher education. *Evolution*, *56*(10), 1891-1901.

American Association for the Advancement of Science. *Benchmarks for science literacy*. Oxford University Press, 1993.

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and evaluation of the conceptual inventory of natural selection. *Journal of research in science teaching*, *39*(10), 952-978.

Asterhan, C. S., & Schwarz, B. B. (2007). The effects of monological and dialogical argumentation on concept learning in evolutionary theory. *Journal of Educational Psychology*, *99*(3), 626.

Barnes, M. E., Elser, J., & Brownell, S. E. (2017). Impact of a Short Evolution Module on Students' Perceived Conflict between Religion and Evolution. *The American Biology Teacher*, *79*(2), 104-111.

Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of research in science teaching*, *27*(5), 415-427.

Blackwell, W. H., Powell, M. J., & Dukes, G. H. (2003). The problem of student acceptance of evolution. *Journal of Biological Education*, *37*(2), 58-67.)

Blake, T. K. (2005). Journaling; An active learning technique. *International Journal of Nursing Education Scholarship*, *2*(1), 1116.

Brewer, Carol A., and Diane Smith. "Vision and change in undergraduate biology education: a call to action." *American Association for the Advancement of Science, Washington, DC* (2011).

Brickhouse, N. W., Dagher, Z. R., Letts, I. V., William, J., & Shipman, H. L. (2000). Diversity of students' views about evidence, theory, and the interface between science and religion in an astronomy course. *Journal of Research in Science Teaching*, *37*(4), 340-362.

Bybee, Rodger W. *Achieving scientific literacy: From purposes to practices*. Heinemann, 88 Post Road West, PO Box 5007, Westport, CT 06881, 1997.

Carter, B. E., & Wiles, J. R. (2014). Scientific consensus and social controversy: exploring relationships between students' conceptions of the nature of science, biological evolution, and global climate change. *Evolution: education and outreach*, *7*(1), 1.

Catley, K. M., & Novick, L. R. (2009). Digging deep: Exploring college students' knowledge of macroevolutionary time. *Journal of Research in Science Teaching*, *46*(3), 311-332.

Cavallo, A. M., & McCall, D. (2008). Seeing may not mean believing: examining students' understandings & beliefs in evolution. *The American Biology Teacher*, *70*(9), 522-530.

Cavallo, A. M., White, K. J., & McCall, D. (2011). The Mismatch among Students' Views about Nature of Science, Acceptance of Evolution, and Evolutionary Science Understandings. *Science Education Review*, *10*(2), 37-42.

Chabon, S. S., & Lee-Wilkerson, D. (2006). Use of Journal Writing in the Assessment of CSD Students' Learning About Diversity A Method Worthy of Reflection. *Communication disorders quarterly*, *27*(3), 146-158.

Cofré, H. L., Santibáñez, D. P., Jiménez, J. P., Spotorno, A., Carmona, F., Navarrete, K., & Vergara, C. A. (2018). The effect of teaching the nature of science on students' acceptance and understanding of evolution: myth or reality?. *Journal of Biological Education*, *52*(3), 248-261.

Crawford, B. A., Zembal-Saul, C., Munford, D., & Friedrichsen, P. (2005). Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. *Journal of research in science teaching*, *42*(6), 613-637.

Dagher, Z. R., & BouJaoude, S. (1997). Scientific views and religious beliefs of college students: The case of biological evolution. *Journal of research in Science Teaching*, *34*(5), 429-445.

Dawkins, R. (2016). *The god delusion*. Random House.

Demastes, S. S., Settlage, J., & Good, R. (1995). Students' conceptions of natural selection and its role in evolution: Cases of replication and comparison. *Journal of Research in Science Teaching*, *32*(5), 535-550.

Deniz, H., & Donnelly, L. A. (2011). Preservice secondary science teachers' acceptance of evolutionary theory and factors related to acceptance. *Reports of the National Center for Science Education*, *31*(4).

Deniz, H., Donnelly, L. A., & Yilmaz, I. (2008). Exploring the factors related to acceptance of evolutionary theory among Turkish preservice biology teachers: Toward a more informative conceptual ecology for biological evolution. *Journal of Research in Science Teaching*, *45*(4), 420-443.

Dobzhansky, Theodosius. "Nothing in biology makes sense except in the light of evolution." (1973): 125-129.

Dunk, R. D., Petto, A. J., Wiles, J. R., & Campbell, B. C. (2017). A multifactorial analysis of acceptance of evolution. *Evolution: Education and Outreach*, *10*(1), 4.

Ertmer, P. A., & Newby, T. J. (1993). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance improvement quarterly*, *6*(4), 50-72.

Farber, P. (2003). Teaching evolution & the nature of science. *The American Biology Teacher*, *65*(5), 347-354.

Fowler, S. R., & Zeidler, D. L. (2016). Lack of evolution acceptance inhibits students' negotiation of biology-based socioscientific issues. *Journal of Biological Education*, *50*(4), 407-424.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of*

Sciences, *111*(23), 8410-8415.

Glaze, A. L., Goldston, M. J., & Dantzler, J. (2015). Evolution in the southeastern USA: Factors influencing acceptance and rejection in pre-service science teachers. *International Journal of Science and Mathematics Education*, *13*(6), 1189-1209.

Glaze, A. L., & Goldston, M. J. (2015). US science teaching and learning of evolution: A critical review of the literature 2000–2014. *Science Education*,*99*(3), 500-518.

Goldston, M. J., & Kyzer, P. (2009). Teaching evolution: Narratives with a view from three southern biology teachers in the USA. *Journal of Research in Science Teaching*, *46*(7), 762-790.

Gregory, T. R. (2009). Understanding natural selection: essential concepts and common misconceptions. *Evolution: Education and Outreach*, *2*(2), 156-175.

Ha, M., Haury, D. L., & Nehm, R. H. (2012). Feeling of certainty: uncovering a missing link between knowledge and acceptance of evolution. *Journal of Research in Science Teaching*, *49*(1), 95-121.

Haslam, S. A. (1997). Stereotyping and social influence: Foundations of stereotype consensus.

Heddy, B. C., & Nadelson, L. S. (2012). A global perspective of the variables associated with acceptance of evolution. *Evolution: Education and Outreach*,*5*(3), 412-418.)

Heddy, B. C., & Sinatra, G. M. (2013). Transforming misconceptions: Using transformative experience to promote positive affect and conceptual change in students learning about biological evolution. *Science Education*, *97*(5), 723-744.

Holt, E. A., Ogden, T. H., & Durham, S. L. (2018). The positive effect of role models in evolution instruction. *Evolution: Education and Outreach*, *11*(1), 11.

Hubbs, D. L., & Brand, C. F. (2005). The paper mirror: Understanding reflective journaling. *Journal of Experiential Education*, *28*(1), 60-71.

Infanti, L. M., & Wiles, J. R. (2014). " Evo in the News:" Understanding Evolution and Students' Attitudes toward the Relevance of Evolutionary Biology. *Bioscene: Journal of College Biology Teaching*, *40*(2), 9-14.

Ingram, E. L., & Nelson, C. E. (2006). Relationship between achievement and students' acceptance of evolution or creation in an upper-level evolution course. *Journal of research in science teaching*, *43*(1), 7-24.

Jensen, M. S., & Finley, F. N. (1996). Changes in students' understanding of evolution resulting from different curricular and instructional strategies. *Journal of research in science teaching*, *33*(8), 879-900.

Jonassen, D. H. (1999). Designing constructivist learning environments. *Instructional design theories and models: A new paradigm of instructional theory*, *2*, 215-239.

Kagan, Dona M. "Implication of research on teacher belief." *Educational psychologist* 27.1 (1992): 65-90.

Kelemen, D., Emmons, N. A., Schillaci, R. S., & Ganea, P. A. (2014). Young children can be taught basic natural selection using a picture-storybook intervention. *Psychological science*, *25*(4), 893-902.

Kim, S. Y., & Nehm, R. H. (2011). A cross-cultural comparison of korean and american science teachers' views of evolution and the nature of science. *International Journal of Science Education*, *33*(2), 197-227.

Lawson, A.E. (1994). Research on the acquisition of science knowledge; epistemological foundation of cognition. Pp. 131-176 in D.L. Gabriel, ed. Handbook of research on science teaching and learning. Macmillan, New York.

Lawson, A. E., & Weser, J. (1990). The rejection of nonscientific beliefs about life: Effects of instruction and reasoning skills. *Journal of Research in Science Teaching*, *27*(6), 589-606.

Lawson, A. E., & Worsnop, W. A. (1992). Learning about evolution and rejecting a belief in special creation: Effects of reflective reasoning skill, prior knowledge, prior belief and religious commitment. *Journal of research in science teaching*, *29*(2), 143-166.

Lerner, L. S. (2001). Good Science, Bad Science: Teaching Evolution in the States. *California Journal of Science Education*, *1*(2), 117-33.

Lombrozo, T., Thanukos, A., & Weisberg, M. (2008). The importance of understanding the nature of science for accepting evolution. *Evolution: Education and Outreach*, *1*(3), 290-298.)

Lord, T., & Marino, S. (1993). How university students view the theory of evolution. *Journal of College Science Teaching*, *22*(6), 353-57.

Lovely, E. C., & Kondrick, L. C. (2008). Teaching evolution: challenging religious preconceptions. *American Zoologist*, *48*(2), 164-174.

Mahner, M., & Bunge, M. (1996). Is religious education compatible with science education?. *Science & Education*, *5*(2), 101-123.)

Manwaring, K. F., Jensen, J. L., Gill, R. A., & Bybee, S. M. (2015). Influencing highly religious undergraduate perceptions of evolution: Mormons as a case study. *Evolution: Education and Outreach*, *8*(1), 1.)

Miller, L. B. (2017). Review of Journaling as a Teaching and Learning Strategy. *Teaching and Learning in Nursing*, *12*(1), 39-42.

Miller, Jon D., Eugenie C. Scott, and Shinji Okamoto. "Public acceptance of evolution." *SCIENCE-NEW YORK THEN WASHINGTON-* 313.5788 (2006): 765.

Moore, R., Brooks, D. C., & Cotner, S. (2011). The relation of high school biology courses & students' religious beliefs to college students' knowledge of evolution. *The American Biology Teacher*, *73*(4), 222-226.

Nadelson, L. S., & Hardy, K. K. (2015). Trust in science and scientists and the acceptance of evolution. *Evolution: Education and Outreach*, *8*(1), 1-9.

Nadelson, L. S., & Southerland, S. A. (2010). Examining the interaction of acceptance and understanding: how does the relationship change with a focus on macroevolution?. *Evolution: Education and Outreach*, *3*(1), 82-88.)

National Association of Biology Teachers (NABT). Mission statement. http://www.nabt.org/websites/institution/index.php?p=1 (2010).

National Research Council, ed. *National science education standards*. National Academy Press, 1996.

Nomme, Kathy M. “Q4B Update.” Presented at the UBC Biology Teaching Program Reterat. July 2014.

Nehm, R. H., & Reilly, L. (2007). Biology majors' knowledge and misconceptions of natural selection. *BioScience*, *57*(3), 263-272.

Nehm, R. H., & Schonfeld, I. S. (2007). Does increasing biology teacher knowledge of evolution and the nature of science lead to greater preference for the teaching of evolution in schools?. *Journal of Science Teacher Education*, *18*(5), 699-723.)

Nehm, R. H., & Schonfeld, I. S. (2008). Measuring knowledge of natural selection: a comparison of the CINS, an open-response instrument, and an oral interview. *Journal of Research in Science Teaching*, *45*(10), 1131-1160.

Oliveira, A. W., Cook, K., & Buck, G. A. (2011). Framing evolution discussion intellectually. *Journal of Research in Science Teaching*, *48*(3), 257-280.

Pew Research Center (2015). Major Gaps Between the Public, Scientists on Key Issues. Washington, D.C., http://www.pewinternet.org/interactives/public-scientists-opinion-gap/, accessed 8 December 2016.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of engineering education*, *93*(3), 223-231.

Raterink, G. (2016). Reflective journaling for critical thinking development in advanced practice registered nurse students. *Journal of Nursing Education*, *55*(2), 101-104.

Rice, J. W., Clough, M. P., Olson, J. K., Adams, D. C., & Colbert, J. T. (2015). University faculty and their knowledge & acceptance of biological evolution. *Evolution:*

Education and Outreach, *8*(1), 1.

Robbins, J. R., & Roy, P. (2007). The natural selection: identifying & correcting non-science student preconceptions through an inquiry-based, critical approach to evolution. *The American Biology Teacher*, *69*(8), 460-466.

Rutledge, M. L., & Mitchell, M. A. (2002). High school biology teachers' knowledge structure, acceptance & teaching of evolution. *The American Biology Teacher*, *64*(1), 21-28.)

Rutledge, M. L., & Sadler, K. C. (2007). Reliability of the measure of acceptance of the theory of evolution (MATE) instrument with university students. *The American Biology Teacher*, *69*(6), 332-335.

Rutledge, M. L., & Warden, M. A. (2000). Evolutionary theory, the nature of science & high school biology teachers: Critical relationships. *The American Biology Teacher*, *62*(1), 23-31.

Scharmann, L. C., & Butler Jr, W. (2015). The Use of Journaling to Assess Student Learning and Acceptance of Evolutionary Science. *Journal of College Science Teaching*, *45*(1), 16.

Scheurman, G. (1998). From Behaviorist to Constructivist Teaching. *Social Education*, *62*(1), 6-9.

Sinatra, G. M., Brem, S. K., & Evans, E. M. (2008). Changing minds? Implications of conceptual change for teaching and learning about biological evolution. *Evolution: Education and outreach*, *1*(2), 189-195.

Sinatra, G. M., Southerland, S. A., McConaughy, F., & Demastes, J. W. (2003). Intentions and beliefs in students' understanding and acceptance of biological evolution. *Journal of Research in Science Teaching*, *40*(5), 510-528.

Smith, M. U., & Siegel, H. (2004). Knowing, believing, and understanding: What goals for science education?. *Science & Education*, *13*(6), 553-582.

Stover, S. K., & Mabry, M. L. (2007). Influences of Teleological and Lamarckian Thinking on Student Understanding of Natural Selection. *Bioscene: Journal of College Biology Teaching*, *33*(1), 11-18.

Stover, S. K., McArthur, L. B., & Mabry, M. L. (2013). Presenting Global Warming and Evolution as Public Health Issues to Encourage Acceptance of Scientific Evidence. *Bioscene: Journal of College Biology Teaching*, *39*(2), 3-10.

Tajfel, H., Turner, J. C., Austin, W. G., & Worchel, S. (1979). An integrative theory of intergroup conflict. *Organizational identity: A reader*, 56-65.

Tajfel, H., & Turner, J. C. (1986). "The social identity theory of intergroup behaviour". In S. Worchel & W. G. Austin (eds.). *Psychology of Intergroup Relations*. Chicago, IL: Nelson-Hall. pp. 7–24.

Tajfel, H. (2010). *Social identity and intergroup relations* (Vol. 7). Cambridge University Press.

Thropp, J. (2017). Using Reflective Journaling to Promote Achievement in Graduate Statistics Coursework. *International Journal of Learning, Teaching and Educational Research*, *16*(1).

Trani, R. (2004). I won't teach evolution; it's against my religion. And now for the rest of the story…. *The American Biology Teacher*, *66*(6), 419-427.)

Turner, J. C., & Oakes, P. J. (1986). The significance of the social identity concept for social psychology with reference to individualism, interactionism and social influence. *British Journal of Social Psychology*, *25*(3), 237-252.

Verhey, S. D. (2005). The effect of engaging prior learning on student attitudes toward creationism and evolution. *BioScience*, *55*(11), 996-1003.

Weisberg, D. S., Landrum, A. R., Metz, S. E., & Weisberg, M. (2018). No missing link: Knowledge predicts acceptance of evolution in the United States. *BioScience*, *68*(3), 212-222.

Weiss, M., & Dreesmann, D. C. (2014). Aspirations and Expectations: Comparing Scientist and Teacher Views as a Source of Ideas for Teaching Evolution. *Universal Journal of Educational Research*, *2*(5), 421-431.)

Wiles, J. R., & Branch, G. (2008). Teachers who won't, don't, or can't teach evolution properly: a burning issue. *The American Biology Teacher*, *70*(1), 6-7.)

Wilson, D. S. (2005). Evolution for everyone: how to increase acceptance of, interest in, and knowledge about evolution. *PLoS Biol*, *3*(12), e364.)

Winslow, M. W., Staver, J. R., & Scharmann, L. C. (2011). Evolution and personal religious belief: Christian university biology-related majors' search for reconciliation. *Journal of Research in Science Teaching*, *48*(9), 1026-1049.

Yates, T. B., & Marek, E. A. (2014). Teachers teaching misconceptions: a study of factors contributing to high school biology students' acquisition of biological evolution-related misconceptions. *Evolution: Education and Outreach*, *7*(1), 1.

Chapter 2

An Examination of Constructivism, Active Learning, and Reflexive Journaling and Their Independent and Combined Effects on Student Acceptance of Biological Evolution

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Abstract

When evolution is not accepted by biology students, biology can easily become little more than a tangential assemblage of facts applied only within the context of the classroom and likely forgotten. Instruction that increases acceptance of evolution is therefore essential to effective biology instruction; however, instruction about evolution is not consistently correlated with increased levels of acceptance. Given that increases are possible, but not universal, maybe the pedagogy utilized in the classroom could influence evolution acceptance. Using a curriculum that demonstrably increases evolution acceptance, we compare multiple pedagogical styles (Behaviorist vs Constructivist, Active vs Less Active, and Journaling vs Not Journaling) in a full-factorial design to test the hypotheses that pedagogy designed for constructivism, active learning and keeping a reflexive journal will increase the probability that students increase in acceptance of evolution with instruction. Though we observed statistically significant acceptance gains, no treatments were statistically different from the other treatments regarding those acceptance gains. Evolution acceptance is possible despite the use of constructivist-designed or behaviorist-designed pedagogy, active learning or less active, keeping a reflexive journal or not, and there is no indication that any combination of these instructional approaches has a greater effect than any other on evolution acceptance.

Introduction

Biology is considered an essential part of a general education [American Association for the Advancement of Science (AAAS) 1993, Brewer & Smith 2011, Bybee 1997, Kagan 1992, National Association of Biology Teachers (NABT) 2010, National Research Council (NRC) 1996]. Given that humans are one of the most influential forces shaping the future of life on earth, it makes sense that a basic education should include an understanding of life and its processes. Learning about any subject is easier when the information fits into an existing schema (Piaget 1976). The entire field of biology is tied together by the theory of evolution [Dobzhansky 1973, AAAS 1993, Brewer & Smith 2011, Bybee 1997, Kagan 1992, NABT 2010, NRC 1996]. If biology is to be understood as a cohesive field of study, then an accurate understanding and application of biological evolution is paramount (Nomme 2014). The AAAS argues that evolution needs to be an essential part of a biology education (NABT 2010). Despite being accepted overwhelmingly by the scientific community (Pew Research Center 2015, Alters & Alters 2001), biological evolution is frequently rejected by the general public (Miller et al. 2006). In many cases, because it is viewed as a source of controversy or because it is rejected by the instructors themselves, biological evolution may be omitted from a biology curriculum (Lerner 2001, Farber 2003, Olivera et al. 2011, Verhey 2005, Goldston & Kyzer 2009) leaving the entire field as little more than a loosely-associated conglomerate of facts to be memorized, repeated, and then forgotten (Nehm & Schonfeld 2007, Nehm & Reilly 2007, Catley & Novack 2009). Even when evolution is taught, students who do not accept evolution do not apply it to situations outside of the classroom (Lerner 2001, Farber 2003, Olivera et al. 2011, Verhey 2005, Goldston & Kyzer 2009). Without acceptance, the teaching of evolution seems futile, and without evolution all of biology becomes far less meaningful and cohesive (Nomme 2014). If biology is to remain a worthwhile part of a general education, then we need to teach evolution so students can accept it in order to fully synthesize biological concepts.

It is hypothesized there should be a positive relationship between classroom instruction about evolution (increase in knowledge of evolution) and an increase in student acceptance of evolution (Anderson et al. 2002; Bishop & Anderson 1990; Demastes et al. 1995; Lord & Marino 1993, Nehm & Schonfeld 2008, Sinatra et al. 2003). Some studies have supported this hypothesis (Robbins & Roy 2007, Akyol et al. 2010; Kim & Nehm 2011; Ha et al. 2012), and some have not (Bishop & Anderson 1990, Demastes et al. 1995, Jensen & Finley 1996, Asterhan & Schwarz 2007, Stover & Mabry 2007, Rutledge & Sadler 2011, Deniz & Donnely 2011, Lawson & Worsnop 1992; Crawford et al. 2005; Cavallo & McCall 2008, Sinatra et al. 2003, Brem et al. 2003, Shtulman 2006, Cavallo et al. 2011). These results suggest that instruction regarding evolution can lead to increased acceptance of evolution, but instruction alone does not necessarily equate to acceptance gains. In other words, not all instruction about evolution brings about equal or even consistent gains. What is the difference between instruction that increases evolution acceptance and instruction that does not? Among the possible explanations for difference in acceptance outcome is the pedagogical style of the instructor (Tanner & Allen 2004). Two of the most popular ideas in education in recent decades have been those of active learning and constructivism (Nehm & Reilly 2007, Alters & Nelson 2002). It has been proposed that teaching using active learning and teaching facilitates the construction of an accurate understanding of evolution that could lead to increased levels of acceptance (Alters & Nelson 2002). It has also been proposed that simple, active, introspective activities such as reflexive journaling could increase acceptance of evolution (Scharmann & Butler 2015).

Constructivism assumes that conceptual understanding is constructed from the interaction of new and old experiences within the mind of the individual (Piaget 1967, Airasian & Walsh 1997, Vrasidas 2000). This contrasts with behaviorism, a learning theory based principally on the increase or decrease of behaviors based upon their relationship to rewards and punishments where intact knowledge can be transferred to learners if they are rewarded properly for demonstrating understanding (Ertmer & Newby 1993). Behaviorism posits that there is an objective reality and knowledge outside of the learner. Constructivism assumes that knowledge is constructed within learners through experience, and that reality and knowledge about reality exist only within the mind of the individual. It also assumes that when using techniques designed to provide that experience for students, the students will show an elevated level of ownership for that conceptual understanding compared to alternative instruction methods. Therefore, it would not be surprising to see that students are more likely to accept concepts they constructed themselves following experience than when information is presented to them without allowing them to conclude that first on their own because of their personal experience (Alters & Nelson 2002).

In a meta-analysis of 225 studies, Freeman et al. (2014) found that using active learning of any kind increased exam scores an average of 6% and that failure rates in STEM courses were 55% higher in non-active courses than in active courses. Active learning was also suggested to increase knowledge and acceptance of evolution specifically by Alters and Nelson (2002) because learning increases in active learning classrooms. As there are concepts taught in the classroom positively correlated with evolution acceptance, such as the nature of science and evolution (Deng et al. 2011, Farber 2003, Dunk et al. 2017), increasing overall learning could increase evolution acceptance. Nehm & Reilly (2007), for example, found that classes taught using active learning strategies such as cooperative learning, inquiry instruction, and small-group discussion achieved higher scores on key concepts of natural selection and had fewer misconceptions than classes taught traditionally.

One of the perceived drawbacks of constructivist pedagogy and active learning in the classroom is the assumption that such techniques are more time consuming and would come at a cost to the total material covered (Oliver-Hoyo et al. 2004). Also, changing an existing non-constructivist class to a constructivist pedagogy generally requires a considerable overhaul to the entire class (Airasian & Walsh 1997), which may prevent many instructors from altering their pedagogical approach. While an increase in acceptance may outweigh these costs, a single active, constructivist technique known as reflexive journaling (Clark & Rossiter 2008) could increase the rate of acceptance both in constructivist classrooms and in more didactic settings designed for behaviorism like those that are more frequently encountered by students.

Journaling is an active learning, constructivist technique that encourages students to reflect on the material being presented in the course, particularly material that introduces a state of doubt or perplexity, and encourages them to find material, including that presented in class, that addresses this doubt (Spalding & Mewborn 2002).

Reflection is defined as the "active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends" (Dewey 1933 p. 9). Boud et al. (1985) further define reflection as “an important human activity in which people recapture their experience, think about it, mull it over and evaluate it” (p. 19). Given that self-reflection is one of the most important aspects of learning according to the Constructivist model (Vrasidas 2000), the objective for the instructor is to encourage students to reconsider their experience, and take the time to evaluate it. Journaling can provide this opportunity to students, and can therefore increase learning (Scharmann & Butler 2015, Chirema 2007, Fosnot 1996, Munday et al 2014, Reynolds 2013, Makaiau et al. 2015, Blake 2005, Wald & Reis 2010, Kuiper & Pesut 2004). Students find that the very act of writing out their thoughts increases the clarity of their ideas on the subject (Pinkstaff 1985) and they have a positive overall opinion of journal writing, viewing that reflective journals assist them in reviewing and critically assessing the importance of the class material (Maypole & Davies 2001, Fritson et al. 2013).

Student journals have been used successfully as a tool to teach evolution and assess evolutionary understanding and acceptance. Scharmann & Butler (2015) found that students journaling about evolution showed an increase in correct ideas regarding evolution over the semester. Though improvement was observed in the course, their experiment only included a single treatment, and therefore it is impossible to determine the actual effect that the act of journaling specifically played in this improvement. Their study included no outside measurement of acceptance of evolution aside from the statements made in the journals themselves. Akkaraju & Wolf (2016) conducted a similar study in which 20 students were frequently engaged in online blogging, which is similar to keeping personal journals. As with the aforementioned study, they observed improvement during the course. This study also was conducted without a control group, making it impossible to see whether the act of journaling was responsible for the increases observed, and measurement of knowledge and acceptance were obtained exclusively from the blog entries themselves and not using any additional instruments. These studies do not demonstrate conclusively that the act of journaling was the source of the change, but the improvements observed could be related to the act of journaling, and that should be determined.

Our study is focused on answering three questions regarding instruction and acceptance of evolution. First, are students taught using pedagogy designed for constructivism more likely to accept evolution than those that are taught using pedagogy designed for behaviorism? Second, are students taught in an active classroom more likely to accept evolution than those taught in a minimally active classroom? And third, are students that keep reflexive journals about the relationship between what they are learning and evolution more likely to accept evolution than those that do not? All three questions were tested in a full factorial quasi-experimental design to determine if any combination of the three led to more increases in acceptance of evolution over other combinations.

Methods

Study population

Our study population consisted of 351 students enrolled in 10 sections of an entry-level, non-major biology class with a heavy focus on evolution and organismal diversity presented in a phylogenetic context. These students were enrolled at a large (~37,000 students), open-enrollment, four-year, public university in the western United States.

Course overview

We developed a curriculum for teaching introductory biology to non-major students. This curriculum consisted of four units that each comprised approximately one quarter of the semester:

Unit 1: Natural Selection, Nature of Science, Cell Structure and Function

Unit 2: Genetics, Mechanisms of Evolution

Unit 3: Phylogenetic Tree Thinking, Non-Vertebrate Diversity and Evolution

Unit 4: Vertebrate Diversity and Evolution, Hominid Evolution

For the final two units, the diversity of organisms was presented in a phylogenetic context.

Question 1: are students taught using pedagogy designed for constructivism more likely to accept evolution than those that are taught using pedagogy designed for behaviorism?

To address this question we randomly assigned entire classes of introductory biology to one of two treatments: Constructivist and Behaviorist. Constructivism is a theory of learning that assumes that knowledge is constructed within the learner and not implanted into the learner from some outside source (Piaget 1967). Operating under this assumption it is impossible to have a wholly non-constructivist classroom. We acknowledge that both treatments may be constructivist regarding how students learn, but that the Constructivist treatment encouraged such construction whereas the Behaviorist treatment did not. Constructivist classrooms were taught using pedagogy that facilitated the personal construction of conceptual understanding by posing questions and experiences to the students giving them time and opportunity to build their own understanding of the content and verifying that correct constructs have been built afterward. It is of note that grades were still assigned based upon exam and other classroom performance, so this design did still have some behaviorist aspects as well.

The general model for instruction in the Constructivist treatment is:

1) A somewhat puzzling example is presented, such as the fact that males of a species are often larger than females of that same species.

2) Students are then asked questions regarding why that might be. They are asked to consider on the question and then to discuss it with the person sitting next to them.

3) Following introspection and conversation, we discuss their answers as a class which will likely leave us with multiple possible hypotheses.

4) We then present more information that can inform their perception regarding the previous questions. In this example, we might observe males fighting over territory where females are present. We observe that the females are disinterested in the fight. We observe that victorious males eventually are the only males to mate (since the other males have been ostracized).

5) Students are now asked to reevaluate their understanding of the initial observation considering what was just observed, and then they would discuss it in pairs. In this example, we would have them discuss why males might be larger than females.

6) Following introspection and conversation, we discuss their answers as a class to ensure that the class has come to a reasonable consensus.

The Behaviorist treatment was similarly student-centered in nature to the Constructivist treatment. We are not testing the impact of student-centered classrooms versus traditional lecture (though that question is also addressed by this study). The Constructivist treatment assists students to construct accurate knowledge. The Behaviorist treatment presents intact knowledge and then rewards the students through affirmation and praise whenever that knowledge is appropriately repeated (Scheurman 1998, Boghossian 2006, Bichelmeyer & Hsu 1999). To ensure that we are testing the style of teaching, and not the activities being used, we utilized the same activities in both treatments. Behaviorist classes were told at the onset what their constructs should be, and the examples (the same examples used in the Constructivist classrooms) were used to illustrate what has been explained. Thus, the fundamental difference was in the order of the presentation and the emphasis placed on contemplation and discussion (see Table 21). Both classes were in all other ways as similar to one another as possible (same days of the week, similar time of day, same semester, etc.).

The general model for instruction in the Behaviorist treatment is:

1) Begin by explaining the reasons for what would otherwise be a puzzling example. Begin by telling the class that males are often larger than females when males compete directly with other males for access to mates.

2) Show the class the example used as the puzzling example in the Constructivist treatment.

3) To ensure that both classes are taught in a student-centered context, have the class reiterate the conclusions presented at the beginning of the discussion in a class discussion on the observation subsequently presented, and make sure to confirm correct responses (reinforcement).

4) Present the further evidence presented in Step 4 of the Constructivist treatment (this time to reinforce the conclusions you provided).

5) Again discuss as a class how this example illustrates the explanation given at the beginning of the discussion, and confirm correct responses (reinforcement).

(Where the students are completing an activity make sure that the conclusions to be drawn from the activity are presented before the activity begins to all students in Behaviorist treatments. The same activities were run in both classes, but Behaviorist treatments never arrived at a desired conclusion not previously provided.)

Question 2: are students taught in an active classroom more likely to accept evolution than those taught in a minimally active classroom?

To test the effect of active learning, we prepared a full factorial design where both the Constructivist and Behaviorist treatments were conducted as both Active and Less Active (see Table 22). The fundamental difference between the Active and Less active designs was that the students in the Less Active classes were not asked to discuss the material with neighbors or the class, and all activities were performed by the instructor and only observed by the students whereas they were performed by the students in the Active class, and students were encouraged to discuss the material. We do not call the Less Active treatment “not active” because even listening and taking notes can be considered active participation (Bonwell & Eison 1991).

Question 3: are students that keep reflexive journals about the relationship of what they are learning and evolution more likely to accept evolution than those that do not?

To address this question we randomly selected from our existing constructivist and non-constructivist sections assigning half of the sections of each treatment to complete a weekly journal entry (see Table 2-3). Students were informed that their grade on the journaling assignment would be based on the thought and consideration they put into their journal entries and not the opinions expressed; they were to be honest about their thinking. Journals were to be about one page, submitted weekly and were to address each of these three topics:

1) What you learned about biology this week.

2) How the things you learned relate to the concept of biological evolution.

3) How your perception of evolution has changed as a result of what you have learned.

Journals were collected weekly, and students were given feedback to encourage them to make sure that they responded to all three prompts and that they were being introspective and considerate in their responses.

Data collection

Data were collected twice during the semester: at the beginning of the semester (before instruction) and at the end of the semester (after instruction). Both surveys were administered using Qualtrics ® software (Qualtrics 2014). These surveys included the Knowledge of Evolution Exam (KEE), an instrument comprised of "10 basic, discriminating questions about evolutionary topics" resulting in scores between 0 and 10 to measure evolution knowledge (Moore et al. 2009 p. 6). They also included the Measure of Acceptance of the Theory of Evolution (MATE; Rutledge & Sadler 2007) which consists of 20 items which in this study were scored on a six option Likert Scale (points were given from 0-5 with possible total scores ranging from 0 to 100, with higher scores indicating greater acceptance) to quantify change in acceptance. The pre-instruction survey also included the Lawson's Classroom Test of Scientific Reasoning (LCTSR) (Lawson, 1978 ver. 2000) that measures scientific reasoning ability on a scale of 0-24. A religiosity instrument (Manwaring et al. 2015) was also included to ensure equivalence in terms of the religiosity of the students. From this instrument, we utilized the five questions regarding the frequency of their religious practices such as prayer and attending religious meetings. Each question has multiple responses that can be scored from least religiously active to most religiously active and when summed can provide an approximation of a participant's level of religious activity. Students were also asked if they believed in god. The latter two instruments and the question about their belief in god were important, as both scientific reasoning and religiosity can be significant predictors of acceptance (Glaze et al. 2015). Both instruments and the question were included in the model as covariates. Additionally included in the survey and the model were demographic questions: gender, age, and whether or not they were a science, technology, engineering, and mathematics (STEM) major.

Data analysis

Data were analyzed for all students that completed both the pre-instruction and post-instruction instruments. The scores were analyzed using a multiple regression approach to determine which factors were statistically correlated with acceptance gains over the semester.

Results

Our study population had an average age of 22 years, with 52.41% male and 47.59% female. They comprised 52.69% STEM majors, and 47.61% non-STEM majors. They had an average LCTSR (scientific reasoning) score of 13.86 out of 24. Religiosity of 47.35 out of 75 with 94.33% reporting a belief in God. The only treatments that considerably deviated from these averages were with respect to the percentage of STEM majors in the Active and Less Active treatments and in the Journaling and Not Journaling treatments (See Table 2 4Across treatments, instruction using the curriculum designed for this study resulted in an increase in MATE (acceptance) scores of 15.29 points on a 100-point scale (t= -17.48, p< .001) with a high effects size (d=1.13) from a pre-instruction mean score of 60.68 out of 100. KEE (knowledge) scores increased by 1.22 points on a 10 point scale (t= -9.75, p< .001) with a medium effects size (d=0.63) from a mean pre-instruction score of 5.56 out of 10.

Question 1 Results: are students taught using pedagogy designed for constructivism more likely to accept evolution than those that are taught using pedagogy designed for behaviorism?

There was no statistically significant difference in increase in MATE scores between Behaviorist and Constructivist treatments with the interactions between the treatments included (p=.605) or without the interactions between treatments included (p=.247) in the presence of the other variables: KEE score before instruction, MATE score before instruction, change in KEE, if the class was taught in an active or less active manner, if they were or were not keeping a reflexive journal, their declared sex, LCTSR score, whether or not they were a STEM major, religiosity score, whether or not they believed in God, and age (see Tables 2-4 and 2 5).

There was also no statistically significant difference in increase in KEE scores between Behaviorist and Constructivist treatments with the interactions between the treatments included (p=.998) or without the interactions between treatments included (p=.437) in the presence of the other variables.

Question 2 Results: are students taught in an active classroom more likely to accept evolution than those taught in a minimally active classroom?

There was no statistically significant difference in increase in MATE scores between Active and Less Active treatments with the interactions between the treatments included (p=.434) or without the interactions between treatments included (p=.586) in the presence of the other variables (see Tables 2-4 and 2-5).

There was also no statistically significant difference in increase in KEE scores between Active and Less Active treatments with the interactions between the treatments included (p=.982) or without the interactions between treatments included (p=.980) in the presence of the other variables.

Question 3 Results: are students that keep reflexive journals about the relationship of what they are learning and evolution more likely to accept evolution than those that do not?

There was no statistically significant difference in increase in MATE scores between Journaling and Not Journaling treatments with the interactions between the treatments included (p=.231) or without the interactions between treatments included (p=.839) in the presence of the other variables (see Tables 2-5 and 2-6). And no interactions of treatments were statistically significant (see Table 2-6).

There was no statistically significant difference in increase in KEE scores between Journaling and Not Journaling treatments with the interactions between the treatments included (p=.241) or without the interactions between treatments included (p=.252) in the presence of the other variables

The only statistically significant predictors of MATE score change were students' pre-instruction KEE (knowledge) score (p<.001) which was directly correlated with MATE change, their change in KEE score from before instruction to after instruction (p<.001) which was also directly correlated with MATE change, and their pre-instruction MATE score (p<.001) which was inversely related to their change in MATE (see Tables 2-4 and 2-5).

The only statistically significant predictors of KEE score change were students' pre-instruction MATE score (p=.001) which was directly correlated with KEE change, their change in MATE score from before instruction to after instruction (p<.001) which was also directly correlated with MATE change, and their pre-instruction KEE score (p<.001) which was inversely related to their change in MATE, and their LCTSR (scientific reasoning) score (p<.001).

Discussion and future directions

Though it has frequently been hypothesized that pedagogical styles designed for constructivism, active learning, and reflexive journaling would increase the probability that students would accept evolution, our results do not support these hypotheses in any combination. We find no statistically significant difference in acceptance as measured by the MATE between constructivist and behaviorist pedagogical styles, active and less active instruction, or journaling or not journaling. The same is true for increases in knowledge as measured by the KEE.

Statistically significant acceptance increases in terms of increase in MATE score were observed across treatments (15.29 points on a 100 point scale from a pre-instruction mean score of 60.68), implying that the curriculum was adequate to produce a change in acceptance, but this change was observed irrespective of the treatment or combination of treatments employed in the classroom. While it can be difficult to compare MATE changes in studies directly [due to differences in the number of response options (5 vs 6) resulting in differences in the total range of scores that are possible (20-100 vs 0-100), and greatly differing initial acceptance rates among other factors], the increase that we observe appears comparable or higher than that observed in other studies where the MATE has been administered both before and after instruction or intervention regarding evolution such as Wiles & Alters (2011) that observed an increase of 12.99 points, Abraham et al. (2012) that observed an increase of 6.00 points, Grossman & Fleet (2017) that observed an increase of 4.2 points, Cofré et al. (2018) that observed an increase of 4.95 points, Ingram & Nelson (2006) that observed increases of 12, 3, and 13 points, Manwaring et al. (2015) that saw a 13.4 point increase, and Nadelson & Southerland (2010) that saw an increase of 3.38 points.

The only statistically significant predictors of MATE change were the student' initial KEE score (how much they knew about evolution entering the course), their KEE change (how much they learned about evolution during the course) and their initial MATE score (how much they accepted evolution at the beginning of the course). Knowledge of evolution was related to acceptance of evolution. The fact that their initial MATE score was inversely related to their change in MATE score is likely related to a ceiling effect (that those with an initially high MATE score had less room for increase). One of the leading criticisms of the MATE is that it may conflate knowledge with acceptance (Smith & Snyder 2016, Smith 2010), and as that may be the case, it could be argued that the correlation between knowledge gains and acceptance gains would be expected when using the MATE. While this is a possibility, it is important to note that the inverse relationship observed between initial MATE scores and change in MATE scores is not observed with initial KEE scores and change in MATE scores where a positive correlation exists. Students with higher initial knowledge scores as measured by the KEE also demonstrated higher, not lower, increases in acceptance as measured by the MATE over the course of the semester. This suggests that, at least in this case, knowledge, as measured by the KEE, and acceptance, as measured by the MATE, are not synonymous.

Given that, in our study, there is no statistically significant evidence that the constructivist pedagogy, active learning, or journaling accounted for the considerable acceptance increase observed, there is still a question as to which factors were of importance. As has been observed in other studies, knowledge of evolution, and increased knowledge of evolution were correlated with an increase in acceptance of evolution in our study (Nadelson & Southerland 2010, Fowler & Zeidler 2016, Glaze et al. 2015). Given that acceptance gains were observed across treatments, it is plausible that many of the factors that were kept constant are related to the increase in acceptance that we observed. These factors include the curriculum and specific examples used in this course, the amount of time dedicated to instruction about evolution, the fact that evolution was used as the unifying theme of the course, the single instructor as a possible role model or as a perceived member of the in-group or groups to which students in the class perceive themselves to belong, or the culture of the classroom as a single in-group without creating in-groups and out-groups within the class.

There is the possibility that the amount of time spent on evolution is an important factor in increasing overall evolution acceptance. However, there is no consistent trend in the literature that increasing the amount of instruction about evolution consistently results in higher acceptance rates among students or instructors (Glaze & Goldston 2015). Thus, it seems more likely that the specific concepts taught, more than the quantity of instruction, may be of greater import with regard to increasing evolution acceptance. Investigating which concepts most influence increase or fail to increase in evolution acceptance as a result of instruction would be of great value in future studies.

There is also a strong possibility that patterns observed in general intergroup behavior could be highly influential in generating or not generating acceptance gains in a classroom. Though the pedagogical styles of the classes differed, the classes were otherwise as similar as possible to control for factors, such as the instructor, that might bias the results. Some key factors we observed about the instructor in this study is that he shared the same religious convictions as the majority of his students. Though this was never mentioned in class, and religion was not a theme of any activity in the course, it was also a fact that was not hidden from the students and something that many students were likely to notice. This study was performed at the same institution with demographically similar students to those observed by Holt et al. (2018) that found that students taught by an instructor that observably shared their religious and cultural convictions were more likely to accept what was being taught than those taught by the same instructor when that instructor concealed this fact.

This result is in perfect harmony with social identity and self-categorization theories in social psychology that explain much about intergroup behavior based on the perceived membership of individuals to relevant social groups, the conditions under which they will identify people, including themselves, as being part of or not part of a group, and the consequences of identifying as such (Turner & Oakes 1986, Tajfel et al. 1979, Tajfel & Turner 1986, Haslam, S. A. 1997). People are generally unreasonably critical of ideas coming from individuals perceived as being outside of their group and unreasonably accepting of ideas coming from individuals perceived as being within their group (Tajfel 2010). This pattern holds true even when the individuals know that their groups were formed arbitrarily (Tajfel 2010), which means that fracturing a class into groups where the teacher is not viewed as part of the in-group could result in reduced credence for what is being presented even if the instructor were otherwise part of the same groups as their students. We observed that this instructor, perhaps deliberately and perhaps by nature, never referred to members of the class as being outsiders. When mention was made to any sort of controversy, the instructor always alluded to the fact that there exist other people out in the world that disagree with the scientific consensus, but never that people in the class disagreed, for example. The class members, from all appearances, were always treated as though they were part of the scientific consensus.

In conclusion, it is apparent that increased levels of student acceptance of biological evolution can be attained as a result of instruction using a wide diversity of pedagogical styles. Though differences may exist based on other measures, we see no statistically significant difference in acceptance or knowledge gains based on the use of pedagogy designed for constructivism or behaviorism, active or less active learning, or whether or not the students are asked to keep a journal. While this study may raise more questions than it can conclusively answer, it certainly confirms that increasing acceptance is possible for instructors that utilize a broad range of teaching styles.

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References

Abraham, J. K., Perez, K. E., Downey, N., Herron, J. C., & Meir, E. (2012). Short lesson plan associated with increased acceptance of evolutionary theory and potential change in three alternate conceptions of macroevolution in undergraduate students. *CBE—Life Sciences Education*, *11*(2), 152-164.

Airasian, P.W. & Walsh, M.E. (1997). Constructivist cautions. Phi Delta Kappan, 78, 444-449.

Akkaraju, S., & Wolf, A. (2016). Teaching Evolution: The Blog as a Liminal Space. *Journal of Effective Teaching*, *16*(2).

Akyol, G., Tekkaya, C., & Sungur, S. (2010). The contribution of understandings of evolutionary theory and nature of science to pre-service science teachers' acceptance of evolutionary theory. *Procedia-Social and Behavioral Sciences*, *9*, 1889-1893.

Alters, B. J., & Alters, S. (2001). *Defending evolution in the classroom: A guide to the creation/evolution controversy*. Jones & Bartlett Learning.

Alters, B. J., & Nelson, C. E. (2002). Perspective: Teaching evolution in higher education. *Evolution*, *56*(10), 1891-1901.

American Association for the Advancement of Science. *Benchmarks for science literacy*. Oxford University Press, 1993.

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and evaluation of the conceptual inventory of natural selection. *Journal of research in science teaching*, *39*(10), 952-978.

Asterhan, C. S., & Schwarz, B. B. (2007). The effects of monological and dialogical argumentation on concept learning in evolutionary theory. *Journal of Educational Psychology*, *99*(3), 626.

Bichelmeyer, B. A., & Hsu, Y. C. (1999). Individually-Guided Education and Problem-Based Learning: A Comparison of Pedagogical Approaches from Different Epistemological Views.

Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of research in science teaching*, *27*(5), 415-427.

Blake, T. K. (2005). Journaling; An active learning technique. *International Journal of Nursing Education Scholarship*, *2*(1).

Boghossian, P. (2006). Behaviorism, constructivism, and Socratic pedagogy. *Educational Philosophy and Theory*, *38*(6), 713-722.

Boud, D., Keogh, R., & Walker, D. (1985). Promoting reflection in learning: A model. *Reflection: Turning experience into learning*, 18-40.

Brewer, Carol A., and Diane Smith. "Vision and change in undergraduate biology education: a call to action." *American Association for the Advancement of Science, Washington, DC* (2011).

Bybee, Rodger W. *Achieving scientific literacy: From purposes to practices*. Heinemann, 88 Post Road West, PO Box 5007, Westport, CT 06881, 1997.

Catley, K. M., & Novick, L. R. (2009). Digging deep: Exploring college students' knowledge of macroevolutionary time. *Journal of Research in Science Teaching*, *46*(3), 311-332.

Cavallo, A. M., & McCall, D. (2008). Seeing may not mean believing: examining students' understandings & beliefs in evolution. *The American Biology Teacher*, *70*(9), 522-530.

Cavallo, A. M., White, K. J., & McCall, D. (2011). The Mismatch among Students' Views about Nature of Science, Acceptance of Evolution, and Evolutionary Science Understandings. *Science Education Review*, *10*(2), 37-42.

Chirema, K. D. (2007). The use of reflective journals in the promotion of reflection and learning in post-registration nursing students. *Nurse education today*, *27*(3), 192-202.

Clark, M. C., & Rossiter, M. (2008). Narrative learning in adulthood. *New directions for adult and continuing education*, *2008*(119), 61-70.

Cofré, H. L., Santibáñez, D. P., Jiménez, J. P., Spotorno, A., Carmona, F., Navarrete, K., & Vergara, C. A. (2018). The effect of teaching the nature of science on students' acceptance and understanding of evolution: myth or reality?. *Journal of Biological Education*, *52*(3), 248-261.

Crawford, B. A., Zembal-Saul, C., Munford, D., & Friedrichsen, P. (2005). Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. *Journal of research in science teaching*, *42*(6), 613-637.

Demastes, S. S., Settlage, J., & Good, R. (1995). Students' conceptions of natural selection and its role in evolution: Cases of replication and comparison. *Journal of Research in Science Teaching*, *32*(5), 535-550.

Deng, F., Chen, D. T., Tsai, C. C., & Chai, C. S. (2011). Students' views of the nature of science: A critical review of research. *Science Education*, *95*(6), 961-999.

Deniz, H., & Donnelly, L. A. (2011). Preservice secondary science teachers' acceptance of evolutionary theory and factors related to acceptance. *Reports of the National Center for Science Education*, *31*(4).

Dewey, J. (1933). *How We Think: A Ristatement of the Relation of Reflective Thinking Yo the Educative Process*. DC Heath and Company.

Dobzhansky, Theodosius. "Nothing in biology makes sense except in the light of evolution." (1973): 125-129.

Dunk, R. D., Petto, A. J., Wiles, J. R., & Campbell, B. C. (2017). A multifactorial analysis of acceptance of evolution. *Evolution: Education and Outreach*, *10*(1), 4.

Ertmer, P. A., & Newby, T. J. (1993). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance improvement quarterly*, *6*(4), 50-72.

Farber, P. (2003). Teaching evolution & the nature of science. *The American Biology Teacher*, *65*(5), 347-354.

Fosnot, C. (1996). Construcvisim: A Psychological Theory Of Learning. In C. Fosnot (Ed.) Constructivism In Theory, Perspectives, And Practice. (Pp. 182-204) New York: Teacher's College Press.

Fowler, S. R., & Zeidler, D. L. (2016). Lack of evolution acceptance inhibits students' negotiation of biology-based socioscientific issues. *Journal of Biological Education*, *50*(4), 407-424.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., &

Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410-8415.

Fritson, K. K., Nelson, D. A., Vontz, H., & Forrest, K. D. (2013). Students' Perceptions of Journaling in Undergraduate Classes. *Journal of Instructional Research*, *2*, 3-9.

Glaze, A. L., Goldston, M. J., & Dantzler, J. (2015). Evolution in the southeastern USA: Factors influencing acceptance and rejection in pre-service science teachers. *International Journal of Science and Mathematics Education*, *13*(6), 1189-1209.

Goldston, M. J., & Kyzer, P. (2009). Teaching evolution: Narratives with a view from three southern biology teachers in the USA. *Journal of Research in Science Teaching*, *46*(7), 762-790.

Grossman, W. E., & Fleet, C. M. (2017). Changes in acceptance of evolution in a college-level general education course. *Journal of Biological Education*, *51*(4), 328-335.

Ha, M., Haury, D. L., & Nehm, R. H. (2012). Feeling of certainty: uncovering a missing link between knowledge and acceptance of evolution. *Journal of Research in Science Teaching*, *49*(1), 95-121.

Haslam, S. A. (1997). Stereotyping and social influence: Foundations of stereotype consensus.

Holt, E. A., Ogden, T. H., & Durham, S. L. (2018). The positive effect of role models in evolution instruction. *Evolution: Education and Outreach*, *11*(1), 11.

Ingram, E. L., & Nelson, C. E. (2006). Relationship between achievement and students' acceptance of evolution or creation in an upper-level evolution course. *Journal of* *research in science teaching*, *43*(1), 7-24.

Ingram, E. L., & Nelson, C. E. (2006). Relationship between achievement and students' acceptance of evolution or creation in an upper-level evolution course. *Journal of research in science teaching*, *43*(1), 7-24.

Jensen, M. S., & Finley, F. N. (1996). Changes in students' understanding of evolution resulting from different curricular and instructional strategies. *Journal of research in science teaching*, *33*(8), 879-900.

Kagan, Dona M. "Implication of research on teacher belief." *Educational psychologist* 27.1 (1992): 65-90.

Kim, S. Y., & Nehm, R. H. (2011). A cross-cultural comparison of korean and american science teachers' views of evolution and the nature of science. *International Journal of Science Education*, *33*(2), 197-227.

Kuiper, R. A., & Pesut, D. J. (2004). Promoting cognitive and metacognitive reflective reasoning skills in nursing practice: self-regulated learning theory. *Journal of Advanced Nursing*, *45*(4), 381-391.

Lawson, A. E. (2000). Classroom test of scientific reasoning: Multiple choice version. Based on A. E. Lawson, "Development and validation of the classroom test of formal reasoning", Journal of Research in Science Teaching, 5(1), pp. 11-24, 1978.

Lawson, A. E., & Weser, J. (1990). The rejection of nonscientific beliefs about life: Effects of instruction and reasoning skills. *Journal of Research in Science Teaching*, *27*(6), 589-606.

Lawson, A. E., & Worsnop, W. A. (1992). Learning about evolution and rejecting a belief in special creation: Effects of reflective reasoning skill, prior knowledge, prior belief and religious commitment. *Journal of research in science teaching*, *29*(2), 143-166.

Lerner, L. S. (2001). Good Science, Bad Science: Teaching Evolution in the States. *California Journal of Science Education*, *1*(2), 117-33.

Lord, T., & Marino, S. (1993). How university students view the theory of evolution. *Journal of College Science Teaching*, *22*(6), 353-57.

Makaiau, A. S., Leng, L., & Fukui, S. (2015). Journaling and Self-Study in an International Research Collective. *Studying Teacher Education*, *11*(1), 64-80.

Manwaring, K. F., Jensen, J. L., Gill, R. A., & Bybee, S. M. (2015). Influencing highly religious undergraduate perceptions of evolution: Mormons as a case study. *Evolution: Education and Outreach*, *8*(1), 1.)

Maypole, J., & Davies, T. G. (2001). Students' perceptions of constructivist learning in a community college american history 11 survey course. *Community College Review*, *29*(2), 54-79.

Miller, Jon D., Eugenie C. Scott, and Shinji Okamoto. "Public acceptance of evolution." *SCIENCE-NEW YORK THEN WASHINGTON-* 313.5788 (2006): 765.

Moore, R, Cotner, S, & Bates, A. (2009). The Influence of Religion and High School Biology Courses on Students' Knowledge of Evolution When They Enter College*. The Journal of Effective Teaching., 9(2), 4–12.*

Munday, J., Sajid, A., & Reader, B. (2014). Cultural Identity Through Art (s) making: Pre-service Teachers Sharing Ideas and Experiences. *Australian Journal of Teacher Education*, *39*(7), n7.

Nadelson, L. S., & Southerland, S. A. (2010). Examining the interaction of acceptance and understanding: how does the relationship change with a focus on macroevolution?. *Evolution: Education and Outreach*, *3*(1), 82-88.)

National Association of Biology Teachers (NABT). Mission statement. http://www.nabt.org/websites/institution/index.php?p=1 (2010).

National Research Council, ed. *National science education standards*. National Academy Press, 1996.

Nehm, R. H., & Reilly, L. (2007). Biology majors' knowledge and misconceptions of natural selection. *BioScience*, *57*(3), 263-272.

Nehm, R. H., & Schonfeld, I. S. (2007). Does increasing biology teacher knowledge of evolution and the nature of science lead to greater preference for the teaching of evolution in schools?. *Journal of Science Teacher Education*, *18*(5), 699-723.)

Nehm, R. H., & Schonfeld, I. S. (2008). Measuring knowledge of natural selection: a comparison of the CINS, an open-response instrument, and an oral interview. *Journal of Research in Science Teaching*, *45*(10), 1131-1160.

Nomme, Kathy M. “Q4B Update.” Presented at the UBC Biology Teaching Program Reterat. July 2014.

Oliveira, A. W., Cook, K., & Buck, G. A. (2011). Framing evolution discussion intellectually. *Journal of Research in Science Teaching*, *48*(3), 257-280.

Oliver-Hoyo, M., Anderson, M., & Allen, D. (2004). Inquiry-guided instruction: practical issues of implementation. *Journal of College Science Teaching*, *33*(6), 20.

Pew Research Center (2015). Major Gaps Between the Public, Scientists on Key Issues. Washington, D.C., http://www.pewinternet.org/interactives/public-scientists-opinion-gap/, accessed 8 December 2016.

Piaget, J. (1967). On the development of memory and identity.

Pinkstaff, E. (1985). An experience in narrative writing to improve public health practice by students. *Journal of Nursing Education*, *24*(1), 25-28.

Reynolds, B. R. (2013). *The impact of transformational leadership, experiential learning, and reflective journaling on the conservation ethic of tertiary-level non-science majors* (Doctoral dissertation, The University of Tennessee at Chattanooga).

Robbins, J. R., & Roy, P. (2007). The natural selection: identifying & correcting non-science student preconceptions through an inquiry-based, critical approach to evolution. *The American Biology Teacher*, *69*(8), 460-466.

Rutledge, M. L., & Sadler, K. C. (2007). Reliability of the measure of acceptance of the theory of evolution (MATE) instrument with university students. *The American Biology Teacher*, *69*(6), 332-335.

Rutledge, M. L., & Sadler, K. C. (2011). University Students' Acceptance of Biological

Theories-Is Evolution Really Different?. *Journal of College Science Teaching*, *41*(2), 38.

Scharmann, L. C., & Butler, W. (2015). The use of journaling to assess student learning and acceptance of evolutionary science. *Journal of College Science Teaching*, *45*(1), 16-21.

Sinatra, G. M., Southerland, S. A., McConaughy, F., & Demastes, J. W. (2003). Intentions and beliefs in students' understanding and acceptance of biological evolution. *Journal of Research in Science Teaching*, *40*(5), 510-528.

Smith, M. U. (2010). Current status of research in teaching and learning evolution: I. Philosophical/epistemological issues. *Science & Education*, *19*(6-8), 523-538.

Smith, M. U., Snyder, S. W., & Devereaux, R. S. (2016). The GAENE—generalized acceptance of evolution evaluation: development of a new measure of evolution acceptance. *Journal of Research in Science Teaching*, *53*(9), 1289-1315.

Spalding, E., Wilson, A., & Mewborn, D. (2002). Demystifying reflection: A study of pedagogical strategies that encourage reflective journal writing. *Teachers College Record*, *104*(7), 1393-1421.

Stover, S. K., & Mabry, M. L. (2007). Influences of Teleological and Lamarckian Thinking on Student Understanding of Natural Selection. *Bioscene: Journal of College Biology Teaching*, *33*(1), 11-18.

Tajfel, H., Turner, J. C., Austin, W. G., & Worchel, S. (1979). An integrative theory of intergroup conflict. *Organizational identity: A reader*, 56-65.

Tajfel, H., & Turner, J. C. (1986). "The social identity theory of intergroup behaviour". In S. Worchel & W. G. Austin (eds.). *Psychology of Intergroup Relations*. Chicago, IL: Nelson-Hall. pp. 7–24.

Tajfel, H. (2010). *Social identity and intergroup relations* (Vol. 7). Cambridge University Press.

Tanner, K., & Allen, D. (2004). Approaches to biology teaching and learning: learning styles and the problem of instructional selection—engaging all students in science courses. *Cell biology education*, *3*(4), 197-201.

Turner, J. C., & Oakes, P. J. (1986). The significance of the social identity concept for social psychology with reference to individualism, interactionism and social influence. *British Journal of Social Psychology*, *25*(3), 237-252.

Verhey, S. D. (2005). The effect of engaging prior learning on student attitudes toward creationism and evolution. *BioScience*, *55*(11), 996-1003.

Vrasidas, C. (2000). Constructivism versus objectivism: Implications for interaction, course design, and evaluation in distance education. *International journal of educational telecommunications*, *6*(4), 339-362.

Wald, H. S., & Reis, S. P. (2010). Beyond the margins: reflective writing and development of reflective capacity in medical education. *Journal of general internal medicine*, *25*(7), 746-749.

Wiles, J. R., & Alters, B. (2011). Effects of an educational experience incorporating an inventory of factors potentially influencing student acceptance of biological evolution. *International Journal of Science Education*, *33*(18), 2559-2585.

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Table 2-1 The basic differences between the instruction in the Constructivist and Behaviorist treatments with their respective sample sizes.

Constructivist Classroom (n=188)	Behaviorist Classroom (n=163)
• Experiences precede conclusions • Conclusions generated by students • Reflection strongly encouraged	• Conclusions precede experiences • Conclusions generated by instructor • Reflection not encouraged

Table 2-2 Representation of the four treatment groups created in the full factorial of the Active vs Less Active and the Constructivist vs Behaviorist treatments with their respective sample sizes.

Treatments (Full Factorial)	
Active/ Constructivist (n=111)	Active/ Behaviorist (n=86)
Less Active/ Constructivist (n=77)	Less Active/ Behaviorist (n=77)

Table 2-3 All eight treatment groups utilized in this study with the total sample size for each treatment.

Treatments (Full Factorial)	
Active Constructivist with Journaling (n=36)	Active Behaviorist with Journaling (n=29)
Active Constructivist without Journaling (n=75)	Active Behaviorist without Journaling (n=57)
Less Active Constructivist with Journaling (n=40)	Less Active Behaviorist with Journaling (n=34)
Less Active Constructivist without Journaling (n=37)	Less Active Behaviorist without Journaling (n=43)

Table 2-4 Mean pre-instruction demographic data by treatment group.

	Active	Less Active	Constructivist	Behaviorist	Journaling	Not Journaling
Religiosity	46.90	47.93	48.14	46.42	47.75	47.07
LCTSR	13.99	13.68	13.65	14.10	14.00	13.76
KEE (Pre-instruction)	5.55	5.57	5.76	5.53	5.66	5.49
MATE (Pre-instruction)	60.96	60.30	59.75	61.75	60.39	60.87
STEM	57.21%	46.71%%	52.63%	52.76%	56.34%	50.24%

Table 2-5 Multiple regression output for all 351 students incorporating all measured variables with MATE Change as the dependent variable.

Model	B	Std. Error	Std. B	t	Sig.
(Constant)	12.1590	3.5860		3.3900	.001
KEE (Pre-instruction)	1.790	.470	.237	3.808	.000
MATE (Pre-instruction)	-.498	.047	-.591	-10.614	.000
KEE Change	1.842	.367	.275	5.017	.000
Journaling	.266	1.310	.009	.203	.839
Active	.711	1.303	.025	.545	.586
Constructivist	-1.484	1.280	-.053	-1.159	.247
Female	.059	1.374	.002	.043	.966
STEM	-.328	1.279	-.012	-.256	.798
LCTSR	.028	.152	.010	.181	.856
Believe in God	3.100	3.301	.051	.939	.348
Religiosity	-.099	.052	-.112	-1.899	.058
Age	-1.020	.198	-.025	-.516	.606

Table 2-6 Multiple regression output for all measured variables including all possible interactions of treatments with MATE Change as the dependent variable.

Model	B	Std. Error	Std. B	t	Sig.
(Constant)	11.443	3.888		2.944	.003
KEE (Pre-instruction)	1.733	.473	.229	3.664	.000
MATE (Pre-instruction)	-5.070	.047	-.602	-10.694	.000
KEE Change	1.811	.369	.271	4.909	.000
Journaling	3.306	2.758	.116	1.199	.231
Active	1.885	2.405	.067	.784	.434
Constructivist	-1.385	2.674	-.049	-.518	.605
Female	.135	1.383	.005	.098	.922
STEM	-2.950	1.280	-.011	-.231	.818
LCTSR	.056	.154	.020	.365	.715
Believe in God	3.103	3.311	.051	.937	.349
Religiosity	-1.070	.053	-.120	-2.038	.042
Age	-.116	.201	-.028	-.579	.563
Journal x Active	-6.460	3.862	-.183	-1.673	.095
Journal x Constructivist	-3.296	3.876	-.098	-.850	.396
Active x Constructivist	-.361	3.366	-.012	-.107	.915
Journal x Active x Constructivist	7.333	5.216	.166	1.406	.161

Chapter 3

Thematic Analysis of Factors That Influence Acceptance or Non-acceptance of Biological Evolution from a Pre-Instruction Position of Non-acceptance

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Abstract

Instruction about biological evolution is not consistently linked to increased levels of evolution acceptance. If acceptance is a goal of instruction, instructors should understand which concepts are most influential regarding change in evolution acceptance. 291 students completing a non-majors, biology class were asked what their position had been regarding evolution before instruction, how their position changed, and why. We then performed a Thematic Analysis on the responses of all students that reported having been unaccepting of evolution before instruction (n=148). The most common responses given regarding why students increased in acceptance (n=136) were that they gained an understanding of phylogenetics and common ancestry, corrected misconceptions, learned the mechanisms of evolution, analyzed examples of evolution, and gained an understanding of the nature of science. The most common responses by those that remained unaccepting (n=12) were that it conflicted with religion, they were willing to accept adaptation but not macroevolution, they were willing to accept evolution but not that humans evolved from monkeys, and that they did not believe the examples presented in class. Understanding the reasons that students give for changing (or not changing) their opinions can greatly shape the way that we approach instruction about evolution in the future.

Introduction

Biological evolution is frequently rejected by students of biology and even by instructors (Lerner, 2001; Farber, 2003; Olivera et al., 2011, Verhey, 2005; Goldston & Kyzer, 2009). Because it is so often rejected and viewed as being controversial, many instructors only cover it briefly, or avoid it entirely (Lerner, 2001; Farber, 2003; Olivera et al., 2011; Verhey, 2005; Goldston & Kyzer, 2009). This presents a problem, because evolution is the foundational concept that ties together the entire field of biology [Dobzhansky, 1973; American Association for the Advancement of Science (AAAS), 1993; Brewer & Smith, 2011; Bybee, 1997; Kagan, 1992; National Association of Biology Teachers (NABT), 2010; National Research Council (NRC), 1996]. Without evolutionary theory, the field of biology becomes, in many ways, a loose assemblage of facts to be memorized without being synthesized into a broader framework (Nomme, 2014). This, unfortunately, is how biology is often viewed by students (Nomme, 2014). Given that biological evolution is almost universally accepted by biologists (Pew Research Center, 2015; Alters & Alters, 2001), the issue with acceptance may simply be that students do not have the knowledge required to accept evolution; accordingly, acceptance should be correlated with instruction on the matter (Anderson et al., 2002; Bishop & Anderson, 1990; Demastes et al., 1995; Lord & Marino, 1993; Nehm & Schonfeld, 2008; Sinatra et al., 2003). This hypothesis has been tested many times, but the results seem to vary considerably; some studies have found that acceptance does accompany instruction (Robbins & Roy, 2007; Akyol et al,. 2010; Kim & Nehm, 2011; Ha et al., 2012), and some have not (Bishop & Anderson, 1990; Demastes et al., 1995; Jensen & Finley, 1996; Asterhan & Schwarz, 2007; Stover & Mabry, 2007; Rutledge & Sadler, 2011; Deniz & Donnely, 2011; Lawson & Worsnop, 1992; Crawford et al., 2005; Cavallo & McCall, 2008; Sinatra et al., 2003; Brem et al., 2003; Shtulman, 2006; Cavallo et al., 2011). Acceptance of evolution does predict the extent to which students will remember and apply their understanding of evolution outside of class (Nehm & Schonfeld, 2007; Nehm & Reilly, 2007; Catley & Novack, 2009). Given this, and since evolution provides the framework to synthesize all fields of biology, if biology is going to be a meaningful, cohesive course of study for students, then acceptance of evolution should be a fundamental objective of instruction.

As acceptance of evolution does, at times, accompany instruction, we know that acceptance gains resulting from instruction are possible, but given that such gains do not always occur, it appears that instruction and acceptance are not directly linked. Perhaps, with respect to acceptance of evolution, not all instruction is created equal. Past studies have revealed some of the important predictors of acceptance in students. These predictors include: understanding of the nature of science (Lombrozo et al., 2008; Heddy & Nadelson, 2012; Glaze et al., 2015; Trani, 2004; Cavallo et al., 2011; Carter & Wiles, 2014), political affiliation (Miller et al., 2006; Carter & Wiles, 2014; Nadelson & Hardy, 2015), a lack of knowledge about evidence and process of evolution (Glaze et al., 2015; Trani, 2004), the presence of misconceptions about evolution (Blackwell et al., 2003; Sinatra et al., 2003), and religiosity (Heddy & Nadelson, 2012; Miller et al., 2006; Carter & Wiles, 2014). Religiosity is a significant predictor of acceptance (Glaze et al., 2015) potentially because there is so often a perceived conflict between biological evolution and theistic positions (Trani, 2004). Because some of these factors are likely addressed in nearly every biology class, and yet not every class gains in acceptance, it is important to understand which concepts actually make an impact on student acceptance of biological evolution.

To answer this question, a thematic was performed using a constant comparison method (Strauss & Corbin, 1998) of the responses to three self-reflective, open-ended essay questions. Questions were administered at the end of an entry-level, non-major biology class at a four-year open-enrollment public university in the Western United States. The goal of the thematic analysis was to analyze the responses from students that described themselves as having not accepted evolution at the beginning of the course, and determine the themes they identified as reasons that they either did or did not become more accepting over the course of the semester. If a pattern exists, there is the potential that courses could be modified in the future to target the concepts that are likely to increase student acceptance and address those that inhibit.

Methods

Study population

Our study population consisted of 291 students enrolled in six sections of an entry-level, non-major biology class at a moderately sized, four-year, public University located in Utah. Students were taught a curriculum consisting of the following units:

Unit 1: Introduction to Natural Selection, Nature of Science, Cell Structure and Function

Unit 2: Genetics, Mechanisms of Evolution (including more detail on natural selection)

Unit 3: Phylogenetic Tree Thinking, Organismal Diversity and Evolution

Unit 4: Vertebrate Diversity and Evolution, Hominid Evolution

For the final two units, the diversity of organisms was presented in the context of phylogenetic trees.

All students were taught by the same instructor, in the same semester and all classes covered the same material.

Verification of acceptance gains

To verify a change in acceptance outside of the statement of the students themselves, all students completed the Measure of Acceptance of the Theory of Evolution (MATE; Rutledge & Sadler, 2007) at the beginning of the course before instruction began, and again at the end of the course after all instruction was completed. The MATE consists of 20 items that were scored on a six-option Likert Scale. Points were given from 0-5 for each item and then summed together with possible scores ranging from 0 to 100 with higher scores indicating greater acceptance. In both instances, the survey was completed as part of a larger Qualtrics (Qualtrics, 2014) survey that was administered online. Students were informed that they would receive points based on having completed the survey. Of the 291 Students who took the final exam, 238 completed both surveys. Students that did not complete both surveys were excluded from this analysis, but not from the thematic analysis.

Questions

On the final exam for the course (following all instruction) all students (n=291) were asked to answer the following questions:

Question 1: What was your opinion of evolution (including human evolution) at the beginning of this class? How has it changed because of what you learned?

Question 2: With respect to altering your opinion of evolution, what was the most important thing that you learned in this class? Why did it matter?.

Thematic analysis

To maximize reliability, all student responses were read and categorized by the same grader. Using Thematic Analysis (Strauss & Corbin, 1998), all responses to the first question were read and categorized as showing a change from an unaccepting opinion to an accepting opinion of evolution, no change from an unaccepting opinion of evolution, or no change from an accepting opinion (there were no examples of individuals changing from an accepting opinion).

Student responses to the second question were analyzed for all students that had, on the first question, reported changing from unaccepting before instruction to accepting after instruction to determine which concepts were most significant to their change of opinion (n=136) and all answers were recorded and categorized based on categories that were generated from the student responses, and new categories were generated for each novel student response until no new responses were observed. Each student response could include one or many factors, and the total number of times each factor was observed was recorded.

This might best be explained using the following examples from actual student responses: *"I used to see evolution (more specifically macroevolution) as something without much evidence. I had been told that we came from monkeys/chimpanzees and that scientists were still looking for the fossil evidence. Since I have learned the real definition of evolution and seen how it works using phylogenetic trees, I understand it and now believe it, being backed up by a lot of evidence."* This response shows a transition from a non-accepting to an accepting position, and demonstrates a corrected misconception about the presence of evidence in support of evolution, a corrected misconception about humans coming from chimpanzees, gaining an understanding of the definition of evolution, and increased understanding tied to understanding phylogenetics. All of these factors would be recorded in reference to a change from not-accepting to accepting.

Student responses to the second question were also recorded and categorized for students that reported that they did not change from an unaccepting opinion for the reasons that they did not change their opinion (n=12) such as in this example: “My religious beliefs heavily influence this question. I don’t think we evolved from monkeys or chimpanzees and the opinion hasn’t changed.” In this example there is a clear lack of change from a position of non-acceptance. The reasons provided were religion and not thinking that humans descended from monkeys or chimpanzees. As before, both factors would be recorded but in this instance with relation to remaining non-accepting.

Results

Results of the MATE

Mean MATE scores increased significantly from 60.3 before instruction to 75.6 after instruction (see Figure 3-1). This was an average increase of 15.3 points (±1.723). All classes observed a significant increase in overall MATE score ($t= -17.48$, $p< .001$, $d= 1.13$). Given that the MATE as administered in this study consisted of 20 items each scored on a six-option Likert scale with each item being worth 0-5 points, scores could range from 0-100 points with 60 points representing the lowest possible mean response accepting of evolution. Any score below this threshold would mean that students are, to some degree, unaccepting of evolution. Before instruction, 129 out of 238 students (54.2%) scored below 60 on the MATE. After instruction, only 31 out of 238 students (13.0%) scored below 60 on the MATE.

Results of thematic analysis

Out of 291 students in the class, 148 (50.86%) made a statement indicating that they did not accept evolution at the beginning of the course. 279 out of the 291 (95.88%) reported that they either still accepted, or had increased in their acceptance of biological evolution as a plausible explanation for the diversity of life on Earth by the end of the semester, whereas only 12 students (4.12%) still reported that they did not accept biological evolution at the end of the course. Thus, of the 148 students that reported that they did not accept evolution before instruction, 136 (91.89%) changed from not accepting to more accepting, and 12 (8.11%) continued to be unaccepting (see Figure 3-2). No students reported having accepted evolution before instruction and changing to a less accepting stance during the semester.

With respect to the 136 students that reported to have changed their opinion of evolution from not accepting to being more accepting, they provided myriad reasons for changing their minds related to the content covered in the course itself. Those reasons fell into one of five broad categories: they gained an understanding of Phylogenetics and common ancestry (Ancestry & Phylogenetics), they corrected prior misconceptions about evolution (Evolution Misconceptions), they came to understand the fundamental mechanisms of evolution (Mechanisms of Evolution), they learned about and considered upon evidences and examples of evolution (Evidence & Examples), and they gained a clearer understanding of the nature of science (Nature of Science). For the relative frequencies of responses fitting each category see Figure 3-3. Each category consisted of multiple, related statements. For a complete list of the statements included in each category and their frequencies see Table 3-1.

Those students that reported having not changed from a position of non-acceptance at the end of the semester listed religion (n=8), acceptance of adaptation but not of macroevolution (n=4), evolution in all organisms but humans are not descended from monkeys (n=3) and that they simply did not believe the examples (n=1) as their reasons for not changing their position.

Discussion

This study supports the hypothesis that instruction about evolution and the nature of science can result in increases in acceptance gains even though this is not universally observed. This was supported by the results of the MATE (showing a mean gain of over 15 points with fewer than 40 points possible to gain). While a direct comparison of studies might not be possible due to differences in the number of response options resulting in differences in the total range of scores that are possible, as well as greatly differing initial acceptance rates and amount of time devoted to evolution in the classroom, the increase observed in this study appears to be comparable or higher than that observed in other studies where the MATE was administered before and after instruction about evolution (e.g. Wiles & Alters, 2011; Abraham et al., 2012; Grossman & Fleet, 2017; Cofré et al., 2017; Ingram & Nelson, 2006; Manwaring et al., 2015; Nadelson & Southerland, 2010). After instruction, only 13% of students fell below the lowest possible mean response accepting of evolution, whereas over 54% fell below that mark at the beginning of the class. There is also evidence that the students were aware of the change that had occurred. As was indicated by the MATE, over half of all students reported in response to the first question [What was your opinion of evolution (including human evolution) at the beginning if this class? How has it changed because of what you learned?] that they had not accepted evolution at the beginning of the class. Also, similar to what was indicated by the MATE, almost 96% reported having experienced some sort of gain in acceptance over the course of the semester.

Knowing that changes in acceptance are possible, but not always correlated with instruction (Bishop & Anderson, 1990; Demastes et al., 1995; Jensen & Finley, 1996; Asterhan & Schwarz, 2007; Stover & Mabry, 2007; Rutledge & Sadler, 2011; Deniz & Donnely, 2011; Lawson & Worsnop, 1992; Crawford et al., 2005; Cavallo & McCall, 2008; Sinatra et al., 2003; Brem et al., 2003; Shtulman, 2006; Cavallo et al., 2011), and knowing that considerable acceptance gains were obtained by these students, and that they show some level of awareness of this change, the answers that they gave to the second question [With respect to altering your opinion of evolution, what was the most important thing that you learned in this class? Why did it matter?] could be of considerable value.

The most frequently mentioned concept by the students contributing to their change of opinion regarding evolution fell within the theme Correcting Misconceptions. That corrected misconception was learning that evolution postulates that extant organisms are derived from common ancestors with other living organisms, and not directly from other organisms living today (n=55). This seemed particularly important when speaking of humans, as many were under the impression that humans were believed to be the direct descendants of chimpanzees or other extant primates. Some even reported that they had, before this course, thought that evolution was the idea that humans evolved from monkeys, and that it did not pertain to any other organisms (n=15). That organisms are the descendants of ancient and not modern life is a common principle taught in classes that cover evolution; in this study it was further reinforced by presenting organismal diversity in the context of phylogenetic trees. Trees, common ancestry, and tree thinking were also commonly referenced as contributing to a change in acceptance (n=62). Non-acceptance of evolution often begins with a false understanding of what it is and how it works (Laidlaw & Jensen, 2019; Pobner, 2016). Directly addressing misconceptions and teaching students to understand Phylogenetics, based on the statements of the students in this study, help them become more accepting of the theory as a whole.

The next most common concept listed by the students, was gaining a greater understanding of the mechanisms of evolution (n=77). Unless a student is only to memorize the abstract definitions of the five primary mechanisms of evolution (mutation, natural selection, non-random mating, genetic drift, and gene flow), they must have a clear understanding of how evolution functions to change the allele frequency in a population over time. In fact, understanding that evolution functions by changing the allele frequency of a population over time was the fourth most cited (n=23) reason reported by students that they increased in acceptance. Once that is understood, they could begin to genuinely conceptualize how the other mechanisms functioned. This understanding of the mechanisms of evolution, after correcting the misconception about common ancestors, was the next most cited reason for increasing acceptance (n=77). Along with a strong understanding of the mechanisms of evolution come three other highly cited ideas that were impactful on the students despite not being emphasized deliberately in the course. These ideas were that evolution is a continuous process (n=15), that it was a process that affects all life (n=15), and that it is not goal oriented or deliberate (n=12). Students who understand evolution understand these concepts as well. As this understanding of how evolution functions were reported as being influential by the students more often than evidences such as fossils or similarities between organisms, it would be of interest to determine to what extent an understanding of these processes is taught versus a simple memorization of definitions, and what effect that may have on the students. However, given what was reported here, we would say that instructors would be well served to teach a deeper understanding of these concepts, and not focus simply on superficial memorization of definitions.

It is true that observable evidences were not reported as frequently as corrected misconceptions (n=81), common ancestry (n=62) or understanding of the mechanisms of evolution (n=77), but that does not mean that these concepts should not be taught. The similarities between organisms and other observable examples and evidences were frequently reported as being critical in the decision to become more accepting of evolutionary theory (n=50). After students gain an accurate conception of what evolution is, and how it works, many students report to accept that evolution occurs, but beyond this, there are many clear and observable examples of phenomena that make much greater sense in the light of evolution. Examples such as similarities between organisms, apparent transitions in the fossil record, human evolution from primate ancestors, the evolution of whales, the evolution of birds from dinosaurs, among others, were examples included in this study frequently referenced by students as being influential.

What was possibly most surprising was that the nature of science, including that science (including evolution) and religion are not mutually exclusive, was the least referenced of all of the ideas mentioned in the essays (n=34). This seems surprising given the impact that between both understanding of the nature of science and reducing perceived conflict between science and religion have on increasing acceptance of evolution (Cofré et al., 2017; Heddy & Nadelson, 2012; Lombrozo et al., 2008, Trani, 2004; Glaze et al., 2015; Cavallo et al., 2011; Carter & Wiles, 2014).

There are many ways to interpret this. One way is that it is not as important to address these concepts as we might have thought. It has been shown that religion is often just an excuse given to mask other misconceptions (Trani, 2004). Perhaps those misconceptions are of far more import. Religion may seem like the biggest obstacle because, as we have seen in this study, it was the most cited reason given by those who refuse to accept evolution. However, again as seen here, those people who let their religious convictions truly prevent them from accepting evolution may be in the extreme (though potentially vocal) minority of students. It is possible that no single course could change their minds. If this is the case, we should not dismiss the importance of covering the nature of science and its limitations at all, as we still saw more people citing non-conflict as the reason they changed than people who cited religion as the reason that they did not. This is in harmony with what has been found in other studies (Manwaring et al., 2015; Gould, 1997; Winslow et al., 2011).

Another way that we could take the fact that the nature of science was the least referenced of all of the ideas mentioned in the essays is that students simply did not recognize the impact that their increased understanding of the nature of science had on their opinion of evolution at the time that their responses were collected. Given that this unit was at the beginning of the course (long before they were surveyed) and was not tied directly to any unit on evolution, it could be that this unit opened the door to acceptance of evolution without the students being cognitively aware that such a change had occurred, or that they had forgotten how influential it had been by the end of the course.

Religion was the most cited reason for continued rejection of evolutionary theory. Except for one person who said that they simply did not believe the examples, all the other reasons implied at least some degree of acceptance of evolution. They either said that they accept adaptation and microevolution, but not macroevolution, or that they accepted that all animals evolve except for humans. Though there is obviously still work to do to if we hope to help students such as these become more accepting of evolution, it is encouraging that they at least accept that the mechanisms that drive evolution are real and functioning currently. This would at least allow them to act as more informed citizens even if their perceptions do not match the current understanding of the scientific community exactly.

Regarding our use of the MATE, there are some concerns that have come up with regard to the MATE as being an accurate measure of evolution acceptance. These concerns include its lack of a clear definition of acceptance, inadequate construct validation, unresolved dimensionality, as well as whether or not the MATE is truly a measure of acceptance or of knowledge of evolution and or religious beliefs (Metzger et al., 2018). This potential conflation with knowledge could explain why some studies have seen clear correlations between measures of knowledge and acceptance (Nadelson & Southerland, 2010; Rice, et al., 2015, Barnes et al., 2019). Many of these concerns have been brought to the forefront since this study was designed and conducted, which led us to question whether it should be repeated using alternative measures, such as the GAENE (Smith et al., 2016) and I-SEA (Nadelson & Southerland, 2012). However, others have observed high levels of correlation between the MATE, GAENE and I-SEA (Metzger et al., 2018, Romine et al. 2018) and concluded there is no need to repeat the experiment or be suspicious of the results using the only MATE (Metzger et al., 2018). In future studies, given that there are potentially meaningful differences between the instruments, it may be wise to implement the use of multiple instruments to measure evolution acceptance (Barnes et al., 2019).

In conclusion, acceptance can accompany instruction on evolution, and, at least within the scope of our sample, there are many concepts that students report to have been influential in the change in acceptance that was both measured using the MATE and reported by the students themselves. According to the students, those concepts fell into the themes of: correcting misconceptions about evolution, the fundamental mechanisms of evolution, Phylogenetics and common ancestry, evidences and examples of evolution, and understanding the nature of science. Understanding which concepts are perceived as being influential for students that became more accepting of evolution, as well as those that did not, could provide key insight that could help shape more effective instruction regarding evolution in the future.

References

ABRAHAM, J. K., PEREZ, K. E., DOWNEY, N., HERRON, J. C., & MEIR, E. (2012). Short lesson plan associated with increased acceptance of evolutionary theory and potential change in three alternate conceptions of macroevolution in undergraduate students. *CBE—Life Sciences Education*, *11*(2), 152-164.

AKYOL, G., TEKKAYA, C., AND SUNGUR, S. (2010). The contribution of understandings of evolutionary theory and nature of science to pre-service science teachers' acceptance of evolutionary theory. *Procedia-Social and Behavioral Sciences*, *9*, 1889-1893.

ALTERS, B. J., AND ALTERS, S. 2001. *Defending evolution in the classroom: A guide to the creation/evolution controversy*. Jones & Bartlett Learning.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE. (1993). *Benchmarks for science literacy*. Oxford University Press.

ANDERSON, D. L., FISHER, K. M., AND NORMAN, G. J. (2002). Development and evaluation of the conceptual inventory of natural selection. *Journal of research in science teaching*, *39*(10), 952-978.

ASTERHAN, C. S., AND SCHWARZ, B. B. (2007). The effects of monological and dialogical argumentation on concept learning in evolutionary theory. *Journal of Educational Psychology*, *99*(3), 626.

BARNES, M. E., DUNLOP, H. M., HOLT, E. A., ZHENG, Y., & BROWNELL, S. E. (2019). Different evolution acceptance instruments lead to different research findings. *Evolution: Education and Outreach*, *12*(1), 4.

BISHOP, B. A., AND ANDERSON, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of research in science teaching*, *27*(5), 415-427.

BLACKWELL, W. H., POWELL, M. J., AND DUKES, G. H. (2003). The problem of student acceptance of evolution. *Journal of Biological Education*, *37*(2), 58-67.)

BREM, S. K., RANNEY, M., AND SCHINDEL, J. (2003). Perceived consequences of evolution: College students perceive negative personal and social impact in evolutionary theory. *Science Education*, *87*(2), 181-206.

BREWER, CAROL A., AND DIANE SMITH. 2011. "Vision and change in undergraduate biology education: a call to action." *American Association for the Advancement of Science, Washington, DC*.

BYBEE, RODGER W. 1997. *Achieving scientific literacy: From purposes to practices*. Heinemann, 88 Post Road West, PO Box 5007, Westport, CT 06881.

CARTER, B. E., AND WILES, J. R. (2014). Scientific consensus and social controversy: exploring relationships between students’ conceptions of the nature of science, biological evolution, and global climate change. *Evolution: education and outreach*, *7*(1), 1.

CATLEY, K. M., AND NOVICK, L. R. (2009). Digging deep: Exploring college students' knowledge of macroevolutionary time. *Journal of Research in Science Teaching*, *46*(3), 311-332.

CAVALLO, A. M., WHITE, K. J., AND MCCALL, D. (2011). The Mismatch among Students' Views about Nature of Science, Acceptance of Evolution, and Evolutionary Science

Understandings. *Science Education Review*, *10*(2), 37-42.

CAVALLO, A. M., AND MCCALL, D. (2008). Seeing may not mean believing: examining students' understandings & beliefs in evolution. *The American Biology Teacher*, *70*(9), 522-530.

COFRÉ, H. L., SANTIBÁÑEZ, D. P., JIMÉNEZ, J. P., SPOTORNO, A., CARMONA, F., NAVARRETE, K., AND VERGARA, C. A. (2017). The effect of teaching the nature of science on students’ acceptance and understanding of evolution: myth or reality?. *Journal of Biological Education*, 1-14.

CRAWFORD, B. A., ZEMBAL-SAUL, C., MUNFORD, D., AND FRIEDRICHSEN, P. (2005). Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. *Journal of research in science teaching*, *42*(6), 613-637.

DEMASTES, S. S., SETTLAGE, J., AND GOOD, R. (1995). Students' conceptions of natural selection and its role in evolution: Cases of replication and comparison. *Journal of Research in Science Teaching*, *32*(5), 535-550.

DENIZ, H., AND DONNELLY, L. A. (2011). Preservice secondary science teachers’ acceptance of evolutionary theory and factors related to acceptance. *Reports of the National Center for Science Education*, *31*(4).

DOBZHANSKY, THEODOSIUS. (1973). "Nothing in biology makes sense except in the light of evolution." 125-129.

FARBER, P. (2003). Teaching evolution & the nature of science. *The American Biology*

Teacher, *65*(5), 347-354.

GLAZE, A. L., GOLDSTON, M. J., AND DANTZLER, J. (2015). Evolution in the southeastern USA: Factors influencing acceptance and rejection in pre-service science teachers. *International Journal of Science and Mathematics Education*, *13*(6), 1189-1209.

GOLDSTON, M. J., AND KYZER, P. (2009). Teaching evolution: Narratives with a view from three southern biology teachers in the USA. *Journal of Research in Science Teaching*, *46*(7), 762-790.

GOULD, S. J. (1997). Nonoverlapping magisteria. *Natural history*, *106*(2), 16-22.

GROSSMAN, W. E., & FLEET, C. M. (2017). Changes in acceptance of evolution in a college-level general education course. *Journal of Biological Education*, *51*(4), 328-335.

HA, M., HAURY, D. L., AND NEHM, R. H. (2012). Feeling of certainty: uncovering a missing link between knowledge and acceptance of evolution. *Journal of Research in Science Teaching*, *49*(1), 95-121.

HEDDY, B. C., AND NADELSON, L. S. (2012). A global perspective of the variables associated with acceptance of evolution. *Evolution: Education and Outreach*,*5*(3), 412-418.)

INGRAM, E. L., & NELSON, C. E. (2006). Relationship between achievement and students' acceptance of evolution or creation in an upper-level evolution course. *Journal of research in science teaching*, *43*(1), 7-24.

JENSEN, M. S., AND FINLEY, F. N. (1996). Changes in students' understanding of evolution resulting from different curricular and instructional strategies. *Journal of research in science teaching*, *33*(8), 879-900.

KAGAN, DONA M. (1992). "Implication of research on teacher belief." *Educational psychologist* 27.1 65-90.

KIM, S. Y., AND NEHM, R. H. (2011). A cross-cultural comparison of korean and american science teachers' views of evolution and the nature of science. *International Journal of Science Education*, *33*(2), 197-227.

LAIDLAW, C., & JENSEN, J. (2019). Why Teach Biology if It Is Rejected? How to Teach Evolution so That It Can Be Accepted. *Bioscene: Journal of College Biology Teaching*, *45*(3), 39-47.

LAWSON, A. E., AND WORSNOP, W. A. (1992). Learning about evolution and rejecting a belief in special creation: Effects of reflective reasoning skill, prior knowledge, prior belief and religious commitment. *Journal of research in science teaching*, *29*(2), 143-166.

LERNER, L. S. (2001). Good Science, Bad Science: Teaching Evolution in the States. *California Journal of Science Education*, *1*(2), 117-33.

LOMBROZO, T., THANUKOS, A., AND Weisberg, M. (2008). The importance of understanding the nature of science for accepting evolution. *Evolution: Education and Outreach*, *1*(3), 290-298.

LORD, T., AND MARINO, S. (1993). How university students view the theory of evolution. *Journal of College Science Teaching*, *22*(6), 353-57.

MANWARING, K. F., JENSEN, J. L., GILL, R. A., AND BYBEE, S. M. (2015). Influencing highly religious undergraduate perceptions of evolution: Mormons as a case study. *Evolution: Education and Outreach*, *8*(1), 1.)

METZGER, K. J., MONTPLAISIR, D., HAINES, D., & NICKODEM, K. (2018). Investigating undergraduate health sciences students' acceptance of evolution using MATE and GAENE. *Evolution: Education and Outreach*, *11*(1), 10.

MILLER, J. D., SCOTT, E. C., AND OKAMOTO, S. 2006. Public acceptance of evolution. *SCIENCE-NEW YORK THEN WASHINGTON-*, *313*(5788), 765.

NADELSON, L. S., AND HARDY, K. K. (2015). Trust in science and scientists and the acceptance of evolution. *Evolution: Education and Outreach*, *8*(1), 9.

NADELSON, L. S., AND SOUTHERLAND S. A. (2010). Examining the interaction of acceptance and understanding: how does the relationship change with a focus on macroevolution?. *Evolution: Education and Outreach*, *3*(1), 82-88.)

NADELSON, L. S., AND SOUTHERLAND, S. (2012). A more fine-grained measure of students' acceptance of evolution: development of the Inventory of Student Evolution Acceptance—I-SEA. *International Journal of Science Education*, *34*(11), 1637-1666.

NATIONAL ASSOCIATION OF BIOLOGY TEACHERS (NABT). 2010. Mission statement. Acessed from http://www.nabt.org/websites/institution/index.php?p=1 on 23 May 2019

NATIONAL RESEARCH COUNCIL, ED. 1996. *National science education standards*. National Academy Press.

NEHM, R. H., AND REILLY, L. (2007). Biology majors' knowledge and misconceptions of natural selection. *BioScience*, *57*(3), 263-272.

NEHM, R. H., AND SCHONFELD, I. S. (2007). Does increasing biology teacher knowledge of evolution and the nature of science lead to greater preference for the teaching of evolution in schools?. *Journal of Science Teacher Education*, *18*(5), 699-723.)

NEHM, R. H., AND SCHONFELD, I. S. (2008). Measuring knowledge of natural selection: a comparison of the CINS, an open-response instrument, and an oral interview. *Journal of Research in Science Teaching*, *45*(10), 1131-1160.

NOMME, KATHY M. 2014. “Q4B Update.” Presented at the UBC Biology Teaching Program Retreat.

OLIVEIRA, A. W., COOK, K., AND BUCK, G. A. (2011). Framing evolution discussion intellectually. *Journal of Research in Science Teaching*, *48*(3), 257-280.

PEW RESEARCH CENTER 2015. Major Gaps Between the Public, Scientists on Key Issues. Washington, D.C., http://www.pewinternet.org/interactives/public-scientists-opinion-gap/, accessed 8 December 2016.

POBINER, B. (2016). Accepting, understanding, teaching, and learning (human) evolution: Obstacles and opportunities. *American journal of physical anthropology*, *159*, 232-274.

QUALTRICS, L. L. C. 2014. Qualtrics [software].

RICE, J. W., CLOUGH, M. P., OLSON, J. K., ADAMS, D. C., AND COLBERT, J. T. (2015). University faculty and their knowledge & acceptance of biological evolution. *Evolution: Education and Outreach*, *8*(1), 1.

ROBBINS, J. R., AND ROY, P. (2007). The natural selection: identifying & correcting non-science student preconceptions through an inquiry-based, critical approach to evolution. *The American Biology Teacher*, *69*(8), 460-466.

ROMINE, W. L., TODD, A. N., AND WALTER, E. M. (2018). A closer look at the items within three measures of evolution acceptance: analysis of the MATE, I-SEA, and GAENE as a single corpus of items. *Evolution: Education and Outreach*, *11*(1), 17.

RUTLEDGE, M. L., AND SADLER, K. C. (2007). Reliability of the measure of acceptance of the theory of evolution (MATE) instrument with university students. *The American Biology Teacher*, *69*(6), 332-335.

RUTLEDGE, M. L., & SADLER, K. C. (2011). University Students' Acceptance of Biological Theories-Is Evolution Really Different?. *Journal of College Science Teaching*, *41*(2), 38.

SHTULMAN, A. (2006). Qualitative differences between naïve and scientific theories of evolution. *Cognitive psychology*, *52*(2), 170-194.

SINATRA, G. M., SOUTHERLAND, S. A., MCCONAUGHY, F., AND DEMASTES, J. W. (2003). Intentions and beliefs in students' understanding and acceptance of biological evolution. *Journal of Research in Science Teaching*, *40*(5), 510-528.

SMITH, M. U., SNYDER, S. W., AND DEVEREAUX, R. S. (2016). The GAENE—generalized acceptance of evolution evaluation: development of a new measure of evolution acceptance. *Journal of Research in Science Teaching*, *53*(9), 1289-1315.

STOVER, S. K., AND MABRY, M. L. (2007). Influences of Teleological and Lamarckian Thinking on Student Understanding of Natural Selection. *Bioscene: Journal of College Biology Teaching*, *33*(1), 11-18.

STRAUSS, A., AND CORBIN, J. 1998. *Basics of qualitative research techniques*. Sage publications.

TRANI, R. (2004). I won't teach evolution; it's against my religion. And now for the rest of the story…. *The American Biology Teacher*, *66*(6), 419-427.)

VERHEY, S. D. (2005). The effect of engaging prior learning on student attitudes toward creationism and evolution. *BioScience*, *55*(11), 996-1003.

WILES, J. R., AND ALTERS, B. (2011). Effects of an educational experience incorporating an inventory of factors potentially influencing student acceptance of biological evolution. *International Journal of Science Education*, *33*(18), 2559-2585.

WINSLOW, M. W., STAVER, J. R., AND SCHARMANN, L. C. (2011). Evolution and personal religious belief: Christian university biology-related majors' search for reconciliation. *Journal of Research in Science Teaching*, *48*(9), 1026-1049.

Figure 3- 1 Mean MATE score before instruction (Pre-MATE) and after instruction (Post-MATE). Error bars depict 95% confidence intervals around the mean

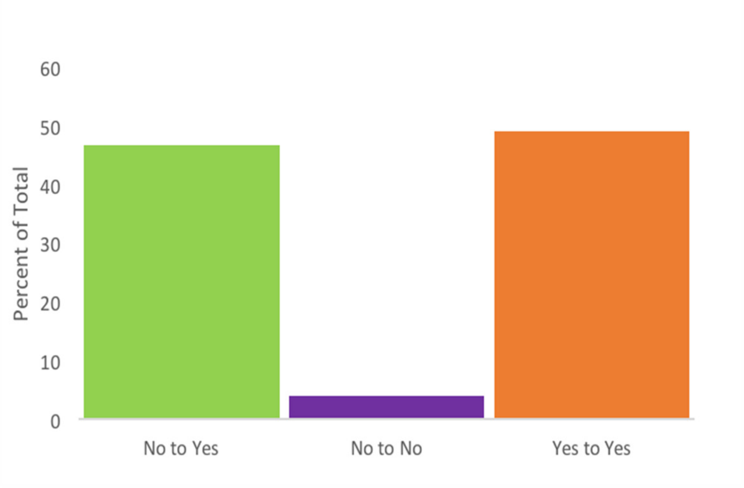

Figure 3- 2 Percentage of students expressing a change from not accepting to more accepting (green), no change from not accepting (purple), and no change from accepting (orange).

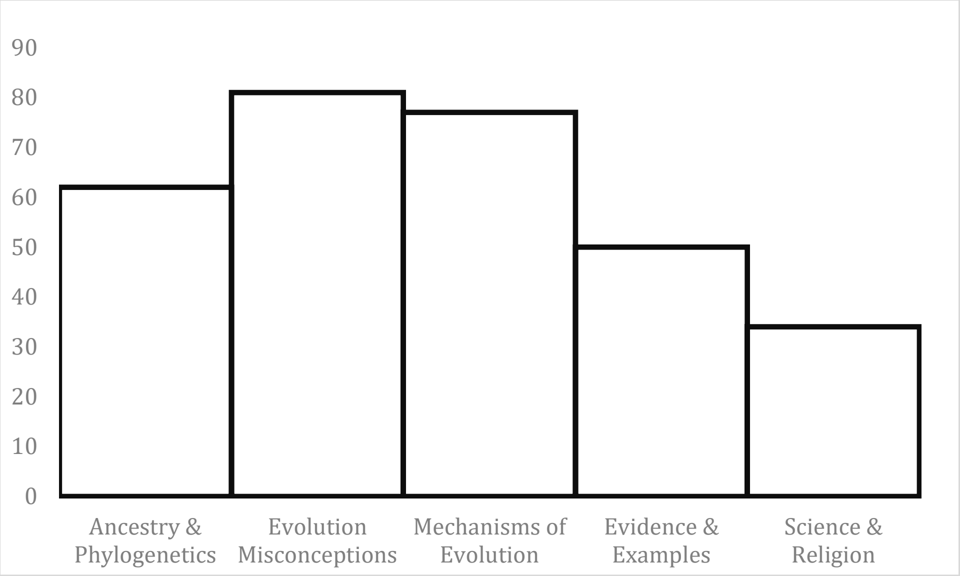

Figure 3- 3 Total frequency of each category of reasons provided by students that changed from being less accepting to more accepting for making that change.

Table 3-1 Complete list of the statements included in each category and their frequencies extracted via Thematic Analysis using a constant comparison method.

Phylogenetics and Common Ancestry (n=62)	Corrected Misconceptions About Evolution (n=81)	Fundamental Mechanisms of Evolution (n=77)	Evidences and Examples of Evolution (n=50)	Understanding of the Nature of Science (n=34)
Common ancestors (45), Phylogenetic trees (17)	Extant species not descendants of other extant species (52), Evolution pertains to all organisms and not just humans (15), Evolution is not deliberate or goal oriented (12), Evolution is not the same as the Big Bang (2)	How the five fundamental mechanisms of evolution work (29), Evolution is a change in allele frequency over time (23)Evolution as a continuous process (15), What fitness is (4), How adaptation works (3), Genetics (1), Inevitability (1), Occurs over a long period of time (1),	Similarities between organisms (14), Evidence (13), Examples (10), Human evolution (6), Vertebrate evolution (4), Selective breeding (2), Makes sense of the world (1)	Science and Religion are not mutually exclusive (21), How science works (8), Limitations of science (3) Definition of a scientific theory (2)

Chapter 4

Concepts That Influence Increases in Student Acceptance of Biological Evolution

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Abstract

Education can result in increases in evolution acceptance. Many studies have observed increases following instruction, but there are also many studies where no such increases are observed. It is apparent that, while instruction can increase acceptance of evolution, not all instruction yields the same results. If acceptance gains are to be consistently observed, instructors must understand which concepts covered in their instruction are likely to be most influential in promoting a change for students that were not initially accepting of evolution. To gain perspective on student thoughts regarding the impact of the concepts covered in a class that produces statistically significant increases in acceptance, we asked students to keep a reflexive journal regarding how the concepts in the class changed their perceptions of evolution. Using thematic analysis on the journals of students that initially demonstrated low levels of evolution acceptance, we found six primary themes that students broadly reported as being important to their acceptance of evolution with two themes being statistically predictive of increases in evolution acceptance. This knowledge could assist instructors in making critical content adjustments to maximize the probability that students will increase in evolution acceptance as a result of instruction.

Introduction

Biology is usually included as part of a general education (AAAS 94, Brewer & Smith 2011, Bybee 1997, Kagan 1992, NABT 2010, NRC 1996). Being biological organisms, it is not unreasonable to consider a basic understanding of living things to be essential for an informed citizenry. Evolution is the most informative theory in all of biology and is often considered to be the central organizing theory of the entire field (Dobzhansky 1973). Despite being so influential, it is often brushed over or avoided completely by biology instructors (Farber 2003, Goldston & Kyzer 2009). This can stem from the fact that instructors, despite being educated in biology, do not accept evolution themselves, or because they are afraid that it will be rejected by their students (Lerner 2001, Olivera et al. 2011, Verhey 2005, Goldston & Kyzer 2009). Without evolution, biology becomes far less interconnected and consequential (Nomme 2014).

Fearing rejection of evolution by students is not an unreasonable concern. A 2019 Gallup poll showed that 38% of Americans believe that humans were created in their current form in the last 10,000 years (Gallup 2019). That number may seem high; this was the lowest percentage recorded in the history of the poll beginning in 1982 (which has oscillated somewhat from a high of 47% in 1993 and 2000, to a previous low of 40% in 2011). It is important to note that the way that these questions are asked could greatly influence the apparent prevalence of such ideas, but across studies the percentage of Americans holding such opinions is considerable (Pew 2019). The Gallup dataset also showed that the percentage of Americans holding the belief that humans were created in their current form in the last 10,000 years decreased with the amount of education respondents had received. It is easy to conclude that instruction on evolution caused the decline, but many studies have found no correlation between instruction and acceptance of evolution (Bishop & Anderson 1990, Demastes et al. 1995, Jensen and Finley 1996, Asterhan & Schwarz 2007, Stover &

Mabry 2007, Rutledge & Sadler 2011, Deniz & Donnely 2011, Lawson & Worsnop 1992, Crawford et al. 2005, Cavallo & McCall 2008, Sinatra et al. 2003, Brem et al. 2003, Shtulman 2006, Cavallo et al. 2011). Though many studies have observed no change in acceptance of evolution following instruction, it is also not uncommon to see statistically significant gains in acceptance as a result of instruction (Robbins & Roy 2007, Akyol et al. 2010, Kim & Nehm 2011, Ha et al. 2012, Holt et al. 2018). Clearly not all forms of instruction on evolution are adequate to effect a change in acceptance, but some are. The key is to identify the difference between effective and ineffective instruction with regard to increasing acceptance of evolution. Acceptance of evolution is essential because when students do not accept evolution, they tend not to apply it outside of the contexts presented in class or to remember what was taught (Lerner 2001, Farber 2003, Olivera et al. 2011, Verhey 2005, Goldston & Kyzer 2009). Given that it is the framework upon which the field of biology is constructed, lack of acceptance of evolution may make the continued instruction of biology difficult to justify as a part of a general education.

One key to understanding the difference between instruction that results in increased evolution acceptance and instruction that does not would be to know which concepts covered in biology courses that discuss evolution are influential in the minds of students. For example, understanding the mechanisms by which evolution occurs, fossil evidence, and the life of Charles Darwin may be concepts that are covered in many biology courses that discuss evolution, but that does not necessarily mean any or all of these concepts actually influence student acceptance of evolutionary theory. Student reflective journals are one way to gain an enriched understanding of the concepts that students found to actually be influential in shaping their perception of evolution. By asking students to keep a record of their experience in class, and which concepts are influential in shaping their opinion of evolution, we can gain some idea which concepts seemed - to the students - to play the biggest role in shaping their opinions on biological evolution over the course of instruction. Reflexive journals could be an excellent means of understanding the thoughts of the students themselves so that instruction can be modified to become more useful in the future (Chabon & Lee-Wilkerson 2006). To gain this perspective, we thematically analyzed the journals of our students to determine if concepts are correlated with an increase or a decrease in acceptance of evolution. Instruction can then be modified to have a greater emphasis on concepts that are influential to elevating evolution acceptance.

Methods

Study Population

Our study population was comprised of 139 students enrolled in 4 sections of an entry-level, non-majors biology class at a moderately sized, four-year, public university located in the Western United States.

Course Description

We developed a curriculum for teaching introductory biology to non-major students that used evolution as an organizing principle. This curriculum consisted of four units:

Unit 1 was Natural Selection, Nature of Science, Cell Structure and Function.

Unit 2 was Genetics, Mechanisms of Evolution.

Unit 3 was Phylogenetic Tree Thinking, Non-Vertebrate Diversity and Evolution.

Unit 4 was Vertebrate Diversity and Evolution, Hominid Evolution.

For the final two units, the diversity of organisms was presented in a phylogenetic context. Each unit comprised approximately one fourth of the semester.

Assessment of Acceptance

To assess acceptance gains, all students completed the Measure of Acceptance of Evolution (MATE; Rutledge and Sadler 2007) instrument at the beginning of the semester (before instruction) and again at the end of the semester (after instruction) as part of a larger Qualtrics (Qualtrics 2014) survey that was administered online. The MATE consists of 20 items that were scored on a six option Likert Scale. Points were given from 0-5 with possible total scores ranging from 0 to 100, with higher scores indicating greater acceptance. We considered scores between 0 and 59 to be representative of low-levels of acceptance. Rutlidge & Sadler (2007) designated all scores under 64 to be either “Low” or “Very Low” acceptance on the MATE. However, they were using a five-option instead of a six-option scale, meaning that their scores could only range between 20 and 100, not 0 to 100 as with our variant of the instrument. 64 out of 100 on such a scale would represent that a student had received 55% of the 80 possible acceptance points on the MATE, and that the student had received an average of 3.2 points per question, meaning that their average answer was just slightly accepting of evolution. Since 3 points were given for neutral answers, anything over 3 would be slightly accepting of evolution. The six-option instrument utilized in this study did not allow for a neutral response. As a result, the scales are not directly comparable, but 59% falls directly between the 55% of points and the 64 out of 100 that were classified as “Low” or “Very Low” using the five-option instrument, and still allowed us adequate sample size for statistical analysis. Students were informed that they would receive points based on having completed the survey but that the number of points would not be influenced by their answers.

There is some question as to whether the MATE is truly a measure of acceptance, or whether it in reality is a measure of knowledge of evolution (Metzger et al., 2018). Such a conflation with knowledge could explain, to some degree, the correlations observed between measures of knowledge and acceptance in past studies (Nadelson & Southerland, 2010; Rice, et al., 2015, Barnes et al., 2019). This potential conflation has particularly been raised since this study was designed and conducted, leading us to question whether it should be repeated using alternative measures, such as the GAENE (Smith et al., 2016) and I-SEA (Nadelson & Southerland, 2012). However, studies comparing these three instruments have observed high levels of correlation between the MATE, GAENE and I-SEA (Metzger et al., 2018, Romine et al. 2018) and have concluded there is no need to distrust the results of experiments that utilized only the MATE (Metzger et al., 2018). That said, given that there are potentially meaningful differences between these three instruments, it may be prudent in future studies to utilize multiple instruments to measure evolution acceptance (Barnes et al., 2019).

Journaling Assignment

All students were asked to complete a weekly journal entry. Journals were to be about one page, submitted weekly, and address each of the following three prompts:

1) What you learned about biology this week.

2) How the things you learned relate to the concept of biological evolution.

3) How your perception of evolution has changed as a result of what you have learned.

Students were informed that their grade on the journaling assignment would be based on the thought and consideration that they put into their journal entries and not the opinions expressed; they were to be honest about their thinking.

Thematic Analysis

Using Thematic Analysis (Strauss and Corbin 1998) responses to the third prompt (how your perception of evolution has changed as a result of what you have learned) were read by five reviewers and each concept mentioned in association with having changed the perception of the student on evolution was recorded. Those themes that were synonymous were grouped together as a single entity on the rubric that was formed. The rubric was then used to evaluate additional journal entries; themes not found on the rubric were recorded and either judged to be synonymous with an existing theme or used to generate a new theme on the rubric. This procedure was repeated until no novel themes arose. Once a final rubric was generated, inter-rater reliability was established by having all raters rate the same journals. Discrepancies were discussed and then a new group of journals were evaluated by all raters until all comparisons of rater scores showed greater than 85% agreement. After this level of agreement had been achieved, raters began official coding. Raters frequently were assigned to score journals that had already been scored by other raters to ensure that reliability did not diminish during the course of the study. At no point was a score of less than 85% agreement observed.

Journals were selected for thematic analysis for all students that scored below 60 out of 100 on the MATE before instruction (i.e., were not accepting) and completed the MATE a second time following instruction (n=42). Raters were aware that the journaling student had not accepted evolution at the beginning of the semester, but they were not apprised of any change in acceptance that may or may not have occurred during the semester.

The rubric used by the graders included 34 themes. However, due to the size of the sample and the high levels of multicollinearity between themes, the rubric was subsequently collapsed down to six broader categories which encapsulated the 34 categories from the rubric. Those categories were the following: Phylogenetics and Common Ancestry, Mechanisms of Evolution, Cellular Biology and Function, The Nature and Limitations of Science, Cellular Biology and Function, and Examples of Evolution.

Phylogenetics and Common Ancestry included concepts such as interpreting phylogenetic trees, constructing phylogenetic trees, homology vs analogy, common ancestry, and monophyly. Mechanisms of Evolution included concepts such as natural selection, mutation, reproduction, Hardy-Weinberg, change in allele frequency over time, non-random mating, genetic drift and gene flow. Cellular Biology and Function included cell structure, organelle function, mitosis and meiosis, cellular respiration, photosynthesis, genetics, gene expression. The Nature and Limitations of Science included concepts such as hypothesis testing, hypothesis vs theory, search for truth, limitations of science, science vs religion, scientific literature and peer review. Examples of Evolution included drug resistance, endosymbiosis, the movement of plants onto land, the vertebrate transition onto land, bird evolution from dinosaurs, eutherian competition with marsupial mammals, whale evolution from terrestrial ancestors, human evolution from simian ancestors, arthropod colonization of land and success as a group.

As an example of how the responses were categorized, a student that, in response to the third prompt (how your perception of evolution has changed as a result of what you have learned), said that “understanding that some genes will get passed on more often than others because they help an animal survive and reproduce more and that is why they become more common made a lot of sense to me. It really helped me see how evolution works, and it made it a lot more believable” would have been marked originally as Natural Selection on the rubric, and as Mechanisms of Evolution on the condensed rubric. Similarly, “…learning that science isn’t just a way to explain the universe without God, but that it doesn’t have the ability to prove that there is a God or isn’t a God helped me feel a lot better about science. It means that I can be okay with evolution without having to throw away my belief in God,” would have been marked initially as Science vs Religion, and subsequently as Nature and Limitations of Science.

Statistical Analysis

We used multiple regression with an alpha of 0.1 to determine if any of the categories of themes mentioned in the journals were predictive of change in MATE score following instruction from a position of low acceptance of evolution (<60 out of 100) before instruction in the presence of the other themes. The two least influential themes were removed from the model to better fit our number of predictors to our sample size. This model revealed two statistically significant positive predictors and one statistically significant negative predictor (see Table 4-1).

RESULTS

In the course as a whole, we observed a mean increase of 14.65 out of 100 points on the Measure of Acceptance of Evolution (MATE; Rutledge and Sadler 2007) from before instruction to after instruction (p=<0.001) (see Figure 4-1), and an even higher mean increase of 19.03 points in our sample group of students that were initially unaccepting of evolution due, at least in part, to the fact that they had lower initial MATE scores than the class as a whole and thus more to gain (see

Figure 4-2). Because the MATE can differ in the terms of the total number of response options (5 vs 6) and therefore in the total range of scores that are possible (20-100 vs 0-100), and because samples can have highly dissimilar initial acceptance (resulting in different amounts of acceptance gains possible), it is difficult to directly compare studies that involve both a pre-instruction MATE and post-instruction MATE score in terms of total effect. Nonetheless, the increase observed in this study is higher than those observed in other such studies involving pre-instruction and post-instruction utilization of the MATE. These studies ranged in change from 3.0 to 13.4 points total from before instruction to after instruction (e.g., Wiles & Alters 2011, Abraham et al. 2012, Grossman & Fleet 2017, Cofré et al. 2018, Ingram & Nelson 2006, Manwaring et al. 2015, Nadelson & Southerland 2010). While this does not necessarily mean that the instruction in our study was in reality more effective than that utilized in these other studies, it is clear that the instruction in this course effectively increased evolution acceptance as measured by the MATE, and is at least comparable to gains observed in other studies.

Six themes emerged from the analysis of the journals as being related to a change in opinion regarding evolution. These themes were: Phylogenetics and Common Ancestry, Mechanisms of Evolution, Cellular Biology and Function, The Nature and Limitations of Science, Diversity of Life, and Examples of Evolution. Phylogenetics and Common Ancestry was reported by 66% of students as having been influential in changing their perception of evolution, Mechanisms of Evolution by 87% of students as being influential, Diversity of Life by 61%, Cell Biology and Function by 58%, the Nature and Limitations of science by 37%, and Examples of Evolution by 53% (see Figure 4-3).

We ran a regression analysis to determine which, if any, of the six themes mentioned predict a statistically significant increase in evolution acceptance, as measured by the MATE. However, given our sample size of 38, we chose to eliminate the two themes with the least effect [Mechanisms of Evolution (p=0.945) and Diversity of Life (p=0.699)] in order to reduce our model to four predictors. Also, due to our relatively small sample size, we made 0.1 the level of significance. Our final model showed three themes to be significant predictors of MATE change: Examples of Evolution, with an increase of 14.32 points in MATE change (p=0.001), Phylogenetics and Common Ancestry with a decrease of 7.97 points in MATE change (p=0.060), and the Nature and Limitations of Science with an increase of 6.897 points in MATE change (p=0.089). Cellular Biology and Function was not significantly predictive in this or any other reduced model (see Table 4-1).

DISCUSSION

There are at least two important stories to pull from these results. First, of all of the concepts covered in this course, there were six emergent themes that students reported as being important in altering their perception of evolution (see Figure 4-3). These themes, in order from most referenced to least referenced, were Mechanisms of Evolution (87%), Phylogenetics and Common Ancestry (66%), Diversity of Life (61%), Cell Biology and Function (58%), Examples of Evolution (53%), and The Nature and Limitations of Science (37%). Not only did students report that these themes were influential in shifting their opinions of evolution, but their acceptance of evolution as measured by the MATE increased quite dramatically (see Figure 4-2). Evolution acceptance increased, and, according to the students, these were the themes that made the difference.

Understanding the mechanisms that drive evolutionary change (mutation, natural selection including sexual selection, gene flow, genetic drift, and non-random mating) was, by a wide margin, the most commonly reported with 87% of students reporting that it was influential in their change of perception. This was, of the six themes, the most directly tied to evolution as this is how evolution observably occurs. Understanding these themes also changes evolution from an abstract phenomenon reported to occur over inconceivably long periods of time, to something clearly observable in the here and now (Alters & Nelson 2002).

Second, though it was the reported position of the students that all six of these factors played a role in their increasing acceptance of evolution, only two of these factors were statistically predictive of increases in MATE score in our models—Examples of Evolution and Nature and Limitations of Science. The influence of the Nature and Limitations of Science was not unexpected given its influence on evolution acceptance in other studies (Cofré et al., 2017; Heddy & Nadelson, 2012; Lombrozo et al., 2008, Trani, 2004; Glaze et al., 2015; Cavallo et al., 2011; Carter & Wiles, 2014), but we might not have predicted that Examples of Evolution would be the most influential theme in our model. In hindsight, it makes sense as people tend to conceptualize anecdotes and stories better than massive stockpiles of evidence and data not couched within a relatable narrative (Clark and Rossiter 2008). The theropod transition into birds is one that is well documented by relatively clear fossil evidence (Zhou 2004). The plant and vertebrate transition onto land are examples used in class where students are asked to predict what changes would need to occur and in what order to allow algae or fish to overcome the factors that tie them to the water. Conveniently, the transitional stages they tend to predict are not only observable in the fossil record, but organisms with very similar morphology and varied dependence on water are still in existence today (Pires & Dolan 2012) making these examples observable by the students themselves. These examples frequently were reported by students as being influential, as was the evolution of birds from dinosaurs and the evolution of whales from terrestrial mammals. While such examples were only reported as being influential by 53% of students, according to our model, students that mentioned this as influential increased MATE change scores by 14.33 points over not mentioning it, in the presence of the other variables (p=.003). It would appear that while these examples are not influential to all students, they are highly influential for those students that make the largest total gains in terms of MATE score.

It was not surprising, given the research indicating that the nature and limitations of science, including the fact that science is not inherently at odds with religion, is so highly correlated with evolution acceptance (Cofré et al., 2017; Heddy & Nadelson, 2012; Lombrozo et al., 2008, Trani, 2004; Glaze et al., 2015; Cavallo et al., 2011; Carter & Wiles, 2014), and that the Nature and Limitations of Science made a measurable impact on acceptance gains in our model. Based on our model, students that mentioned themes related to the Nature and Limitations of Science scored 6.90 points higher than had they not mentioned such themes in the presence of the other variables. What was surprising was that this was the least mentioned by students of the six themes as being influential in their change of position. It appears that few students were able to make a direct link between this and evolution, but those that did made substantial acceptance gains as measured by the MATE. So the question is clearly, why is it that so few students made this connection if it is so influential on those that do? It could be due to the placement of this unit in the curriculum. While the nature of science remains a theme throughout the course, it is one of only two themes discussed primarily before our unit on evolution (except for natural selection which was discussed on the first full day of instruction). Thus, students that compartmentalize the material covered in the class may not be thinking about these concepts later in the class when evolution was being covered. The only other theme taught principally before the evolution unit was Cell Biology and Function which includes basic cell replication and a brief introduction to mutation, though the full impact of mutation on evolution was only taught explicitly during instruction on the Mechanisms of Evolution. It could also be that a large percentage of students simply did not understand or internalize the material taught regarding the nature of science, and that only those that understood the nature of science to a point that they could apply that understanding later in the course were able to make connections that led to increases in evolution acceptance. Or it could be that many students already understood the nature of science, and thus the material covered was not new, and any influence that it may have had on their acceptance occurred before the beginning of the course. In future studies it would be valuable to include a measure of understanding of the nature of science in both the pre-instruction and post-instruction instrument in order to tease this out.

Mechanisms of Evolution and Phylogenetics and Common Ancestry, perhaps the two most conspicuously related themes to evolution, were the most referenced of all by students as being influential. Surprisingly, however, Mechanisms of Evolution had no predictive ability with regard to changes in acceptance as measured by the MATE, and students that found Phylogenetics and Common Ancestry influential demonstrated lower gains than would have been predicted had this theme not been mentioned. This could be because this theme was only novel and influential to students that made comparatively small gains, or possibly because phylogenetics can potentially introduce misconceptions about evolution that could reduce acceptance (Kummer et al. 2016). Whether this theme is positively influential to students that are otherwise making the smallest acceptance gains, or actually impedes acceptance is a question that should be addressed by further research as the frequency with which Phylogenetics and Common Ancestry and the Mechanisms of Evolution were perceived as being influential by the students cannot be overlooked. Why were these themes so frequently referenced as being influential by the students themselves without that influence being reflected in terms of acceptance gains? It may be that these concepts are so clearly related to evolution that it was easy for students to see their applicability, but that their actual influence on acceptance as measured by the MATE was not very large (or negative). It could also be that these concepts were more emphasized in class or taught for more time, increasing their appearance in the journals, whether they did or did not have much of a positive impact on the students' actual perception of evolution. Organismal Diversity and Cell Biology and Function were additionally mentioned by the students more frequently than were Nature and Limitations of Science or Examples of Evolution (the two positive, statistically significant factors in our model), and yet the effects of these factors also were not statistically significant. This could shine considerable light on the reasons why some evolution instruction, while clearly tied to knowledge of evolution, does not result in changes in acceptance of evolution (Bishop & Anderson 1990, Demastes et al. 1995, Jensen and Finley 1996, Asterhan & Schwarz 2007, Stover & Mabry 2007, Rutledge & Sadler 2011, Deniz & Donnely 2011, Lawson & Worsnop 1992, Crawford et al. 2005, Cavallo & McCall 2008, Sinatra et al. 2003, Brem et al. 2003, Shtulman 2006, Cavallo et al. 2011).

To increase evolution acceptance in students, based on these results, we would recommend that a broad focus across all six themes is still important, given that students mentioned these themes throughout their journals as being influential on their position on evolution (Mechanisms of Evolution, Phylogenetics and Common Ancestry, Diversity of Life, Cell Biology and Function, Examples of Evolution, and The Nature and Limitations of Science). However, our data also highlight the importance of the two mechanisms that were statistically significant according to our model. It may be that some of the concepts that are less obviously related to evolution are of greatest value with regard to increasing evolution acceptance. Examples of evolutionary transitions such as the evolution of land plants, land vertebrates, whales and birds should be used clearly and often, as well as an emphasis on understanding the nature of science and its connection with evolution are two candidate themes that might result in the largest total acceptance gains.

Even though our data indicate that evolutionary examples and understanding of the nature and limitations of science can play a sizeable role in increasing evolution acceptance, it is not entirely clear why they make such a large impact on some students while not being reported as having an impact at all on others. Do the specific examples determine which students most benefit? Is there something that can be done to make this benefit apply to a greater proportion of the class? There are many such questions that should be addressed in future research.

CONCLUSIONS

We have been able to identify, using thematic analysis of journals, six basic concepts that students report to have had an effect on their acceptance of evolution. Two of these themes were statistically significant, according to our model, and were predictive of increases in evolution acceptance as measured by the MATE. While examples of evolutionary transitions and the nature and limitations of science may not have had the broadest effect in terms of the number of students affected, it does appear that they had the most profound effect on evolution acceptance of any of the six themes reported by the students as being influential. Instructors that desire increases in evolution acceptance should continue to address a broad array of evolutionary themed concepts, with emphasis on clear examples of evolutionary transitions and on an understanding of the nature and limitations of science.

Table 4-1 Multiple regression model of factors that are predictive of Change in MATE score from before instruction to after instruction with the percentage of students referencing each theme as being influential. Adjusted R Square = .240.

Model	B	Std. Error	Standardized B	T	Sig.	Freq.
Constant	17.309	4.043		4.281	<0.001	
Phylogenetics and Common Ancestry	-7.947	4.088	-0.295	-1.944	0.060	64%
Cell Biology and Function	-5.421	3.909	-0.209	-1.387	0.175	60%
Nature and Limitations of Science	6.897	3.939	0.260	1.751	0.089	38%
Examples of Evolution	14.332	3.933	0.559	3.644	0.001	48%

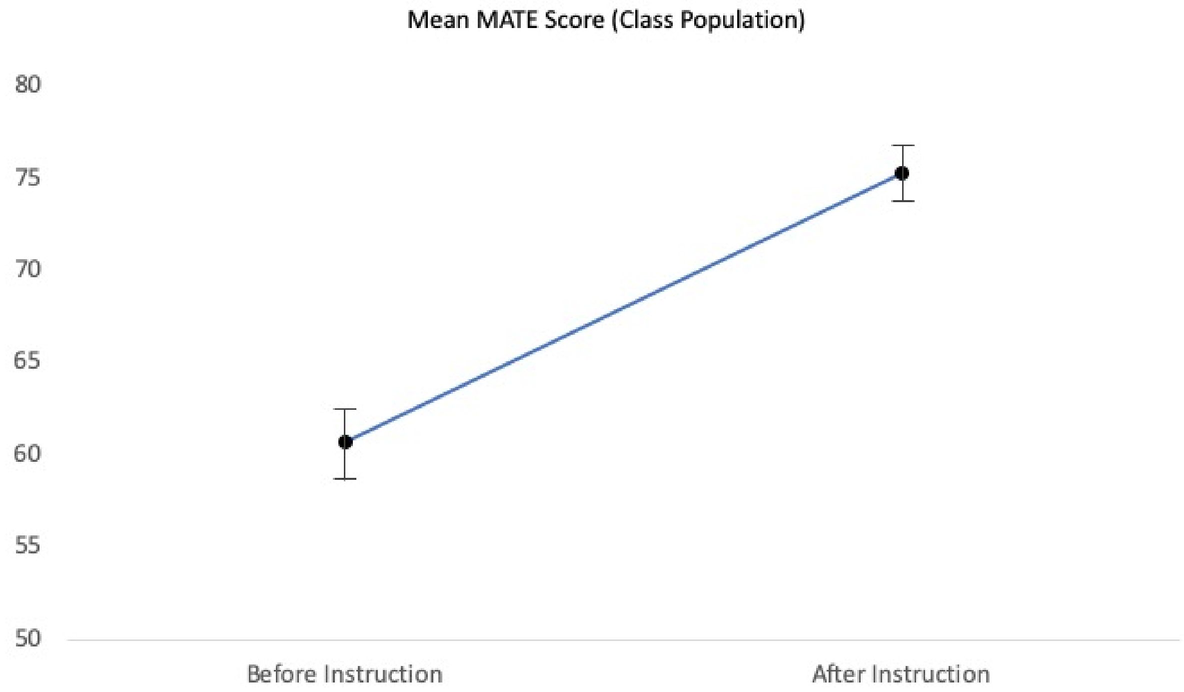

Figure 4-1 Mean MATE score for all students enrolled in the course from before instruction to after instruction. Error bars represent 95% confidence intervals.

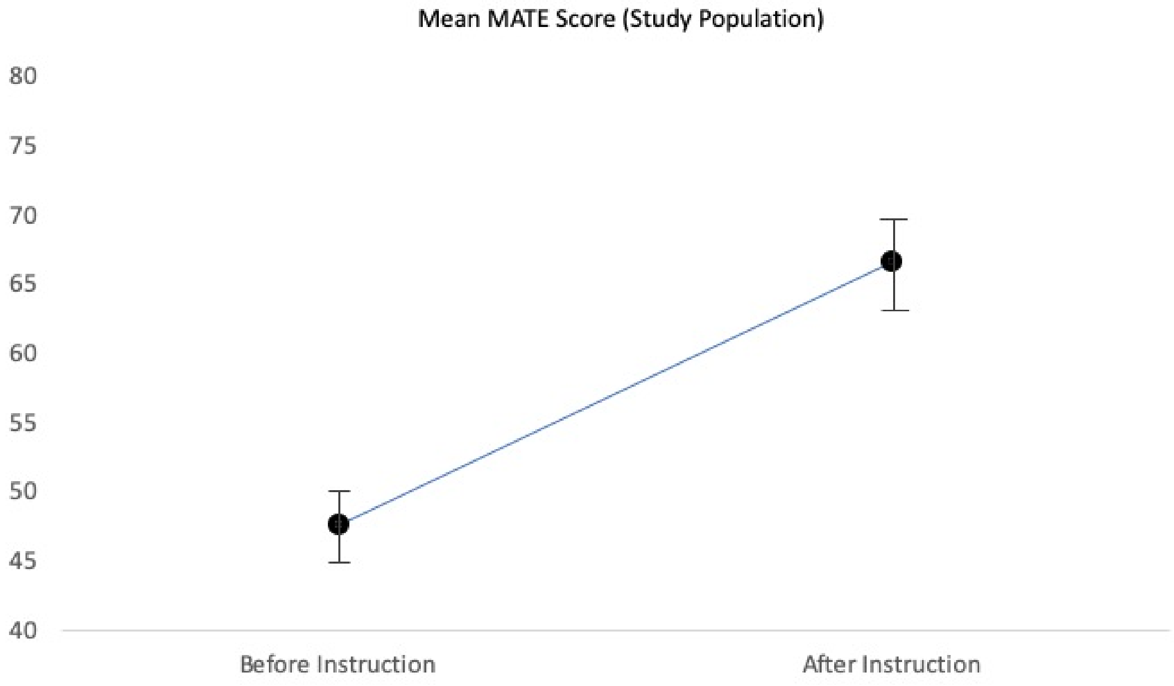

Figure 4-2 Mean MATE score for the study population from before instruction to after instruction. Error bars represent 95% confidence intervals.

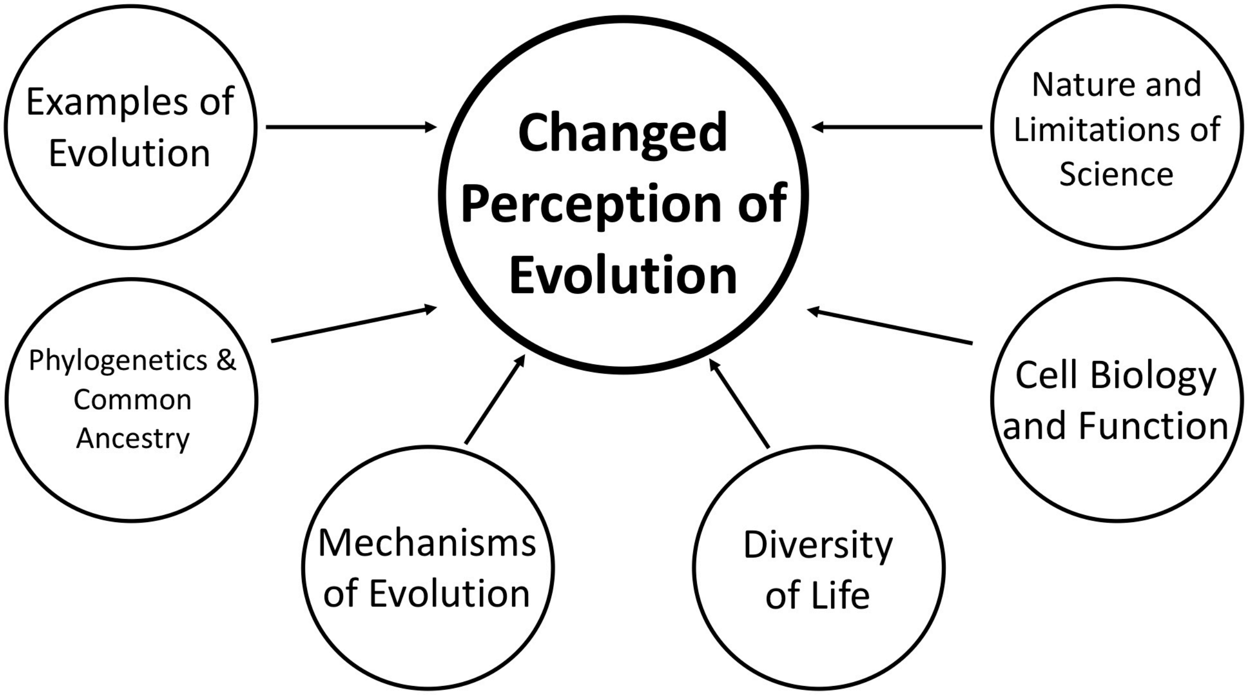

Figure 4-3 Factors reported by students in reflexive journals as being influential in changing their perception of evolution.

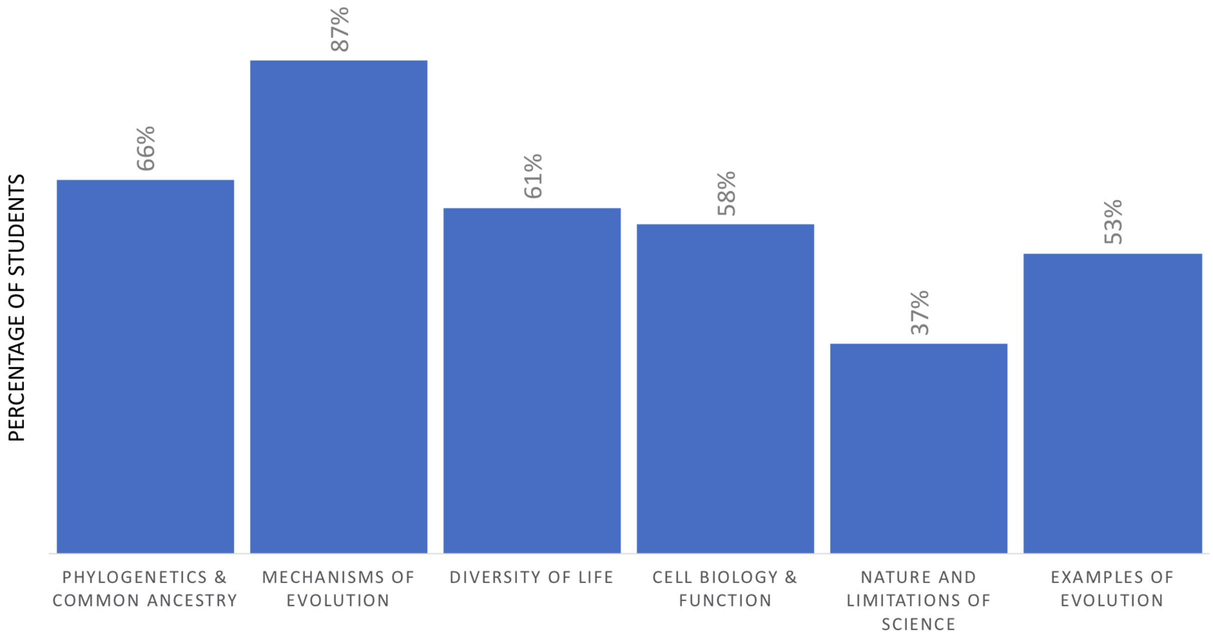

Figure 4-4 Percentage of students reporting each factor as being influential in changing their perception of evolution.