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Evolution Acceptance, Religiosity, and Nature of Science in an Undergraduate Population

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Abstract

Decades of research into the acceptance of evolutionary biology have revealed a number of factors that are related to an individual's choice to accept or reject evolutionary biology. This work seeks to extend that work in the following key ways: (1) Use a longitudinal time frame, along with multifactorial linear modeling, to investigate the changes in evolution acceptance and its associated factors across a year of introductory biology education. (2) Expand the study population to a general undergraduate population, and study the change in acceptance of evolution in this general student population across the first semester of university education. (3) Use qualitative methods to interview students from the general undergraduate population to gain a more nuanced understanding into the specific reasons individuals choose to accept or reject evolutionary biology.

Results from this work show that students enrolled in introductory biology and a more general student population have very similar associations between their acceptance of evolution and related variables. Specifically, changes in students' acceptance of evolution is positively and significantly related to changes in their knowledge of evolution and understanding of the nature of science, while increasing acceptance of evolution is significantly related to a decrease in religiosity. Upon interview, students were able to articulate well how their religious views influenced their acceptance of evolution, but did not discuss as much about how their understanding of science influenced their acceptance of evolution. Together, these results help us to understand the reasons behind an individual's acceptance or rejection of evolutionary biology, while showing areas that are ripe for future study.

Evolution Acceptance, Religiosity, and Nature of Science in an Undergraduate Population

or, Want acceptance of evolution? Think NOSCRUBS (Nature Of SCience and Religiosity, in Undergraduate Biology Settings)

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Introduction

Biological evolution, here considered as the change in living forms largely via the mechanism of natural selection, is such a fundamental concept in biology that Theodosius Dobzhansky, geneticist and founder of the modern evolutionary synthesis, once claimed, "nothing in biology makes sense except in the light of evolution (Dobzhansky, 1973)." This means that concepts that rely on biology, such as vaccinations, public health, and the impacts of climate change on the worlds' ecosystems, all require an understanding of evolution.

Evolution is somewhat unique among scientific topics in that we can discern a difference between *understanding* of the topic and *acceptance* of it. We would not generally concern ourselves with this in a topic like photosynthesis; while individuals may not know much about photosynthesis, they do not often reject its existence. However, there is a prominent rejection of evolution, especially in countries like the United States (Miller et al., 2006), where more than 40% of adults surveyed rejected any place for evolution in how humans came to be (Gallup, 2014).

While it is certainly possible that individuals can understand evolution without accepting it, it seems likely that those who accept evolution and integrate it into their worldview will be more likely to make choices based on their evolutionary knowledge, leading to better outcomes for, say, antibiotic treatment. It is for this reason that the current recommended strategy includes teaching towards acceptance of evolution (Dunk et al., 2019), as long as there is no *requirement* to accept. Thus, research into the reasons for acceptance or rejection of evolutionary biology is valuable not only for its own inherent interest, but in support of identifying potential pedagogical targets for intervention towards increasing acceptance. In reality, this seems to have been the goal of evolution acceptance in its past couple decades, but having the current recommendation of over 20 evolution education experts (ibid.) helps to clarify this as a path forward.

Previous work in understanding evolution acceptance has identified a plethora of variables associated with (and possibly explaining) evolution acceptance. The two most commonly investigated are knowledge of evolution and religious considerations. This sets up a simple explanation for the difference between evolution and so many other biological phenomena in terms of acceptance– for evolution, knowledge leads to acceptance only when religion does not hinder that. The interaction between these two factors is often presented in popular science literature as the whole reason behind rejecting evolution (Coyne, 2009), perhaps reflecting the popular discourse on the subject. It is indeed true that both knowledge of evolution and religious views are importantly related to acceptance of evolution (Dunk et al., 2019; Pobiner, 2016), but the overall problem seems to be more nuanced, with additional factors showing significant, independent relations to acceptance of evolution. Chief among these is an understanding of the nature of science (NOS), roughly described as the aims and processes of science, though NOS understanding and conceptions defy easy description (Abd-El-Khalick and Lederman, 2000).

These three variables– knowledge of evolution, religious views, and understanding the nature of science– seem to fit together the best to model acceptance of evolution (Dunk et al., 2019). Higher knowledge of evolution and higher understanding of the nature of science are associated with higher evolution acceptance, while religious views[1] tend to lead to lower acceptance. Additional psychological variables related to intellectual curiosity, open-

[1] Religious views are, of course, highly variable, and so the effect differs based on a host of factors. In most studies, however, the majority of participants are from Abrahamic religions which share a creation story, which itself forms the crux of most religious opposition to evolutionary biology. Thus, looking at religiosity (defined loosely as the intensity and importance of religious views) offers a more balanced and useful way to operationalize this, though denominational differences seem to have an additional relation to evolution acceptance.

mindedness, etc. seem to have some added effect, but their inclusion is highly variable, disallowing their precise effect to be readily discerned.

When I, along with my colleagues, formalized this model (Dunk et al., 2019), we included a host of recommendations for the future of evolution education research. Two of these were to diversify sampling efforts and to use longitudinal time frames. Diverse sampling efforts allow us to be more confident in the generalizability of these relationships, ensuring that decisions made on the basis of this model would be (or at least attempt to be) of equal benefit to all. Longitudinal time frames help us to be confident that acceptance of evolution and these associated variables are tied together, not merely associated at one point in time. While this is not direct evidence of causation, and work demonstrating causation should be a future goal for evolution education research, it suggests that those variables changing in concert with acceptance of evolution would be good potential targets for educational intervention, where appropriate.

This dissertation seeks to answer, in part, those challenges. In the first chapter, we use a longitudinal time frame to explore acceptance of evolution in students across a year of introductory biology education. We surveyed students at the beginning and end of the year and regressed the change in their acceptance of evolution on their change in key variables, including the major components described above. We also ran large linear models to determine the relative contributions knowledge of evolution, religiosity, understanding the nature of science, and other measures had on explaining variance in the acceptance of evolution at both the beginning and end of the year. This chapter is in a third round of revision at the *Journal of Research in Science Teaching*.

The second chapter adds diversity to this first study by expanding the study population to a full undergraduate cohort. Students in the first year experience program in Arts & Sciences at

Syracuse University were offered to take part in the survey as part of their course experience. We used very similar survey measures to the first study, though we made additions and refinements as necessary. Here, in addition to the single regressions, we used a stepwise regression to build a multiple regression model to model the independent association between each changing variable and change in acceptance of evolution. Though this study used a population that was much more general, instead of students in a biology classroom, we found very similar results to that in the first chapter, with notable exceptions that are discussed in the chapter. This chapter is in the final stages of preparation for *CBE: Life Sciences Education* and the results have been presented at international conferences, including Evolution 2019.

The third chapter takes a different approach from the first two and uses qualitative methods to explore students' reasons for their acceptance of evolution. This was borne out of a desire to add nuance and context to the discussion of evolution acceptance. Quantitative methods are good for modeling, as they are used in the first two chapters, but they fail to capture diverse and individualized perspectives, as their very mechanics serve to explain variance using the fewest number of variables possible. Qualitative methods, instead, center individual experiences, while still seeking to understand common themes. Further, qualitative methods, especially the open-ended interviewing used in this dissertation, allow for participants to choose their own words and thoughts to describe experiences, rather than surveys that present pre-worded statements and seek agreement levels. Chapter 3 presents the results of interviews with a subset of students surveyed in chapter 2 and asks students to discuss things they feel make/made them more or less accepting of evolution. Though these methods differed from chapters 1 & 2, the themes we saw in this chapter complimented the factors associated with evolution acceptance in the first two chapters. Exploring the reasons for students' acceptance of evolution using both qualitative and quantitative methods adds validation to all the results, as well as allows us to explore both in detail and broadly what experiences and understandings contribute to these students' acceptance of evolution. The results from this chapter were accepted for presentation at the 2020 Annual International Conference of the National Association for Research in Science Teaching (via double-blind peer review of a 5-page research summary), as well as the 2020 international meeting of the Society for the Advancement of Biology Education Research.

Together, these chapters begin to respond to the challenge brought for the future of evolution education. They do so by applying a longitudinal time frame, generalizing the studied population, and adding context to results via qualitative methods. Despite these additions, the results found are mostly in agreement with previous research, which shows that acceptance of evolution is associated most strongly with knowledge of evolution, understanding the nature of science, and religiosity.

Chapter 1. Changes in acceptance of evolution and associated factors during a year of introductory biology: The shifting relations of biology knowledge, politics, religion, demographics, and understandings of the nature of science

1.1 Introduction

Evolution is the unifying theme of all biology, through which living organisms and communities can be understood most clearly (Dobzhansky, 1973). This framework for the life sciences is reflected in the overwhelming acceptance of evolution amongst biologists (Graffin, 2003). However, acceptance of evolution is not nearly as universal amongst members of the general public as it is in the scientific community. Despite decades of reform to improve evolutionary understanding, in the United States little change has been seen in the number of people who accept evolutionary explanations of life's diversity as compared to supernatural ones (Gallup, 2014).

Rejection of evolution and the theory around it may lead to an inability to understand and to reason about biology as it is studied, understood, and applied by working biologists (Dobzhansky, 1973). The ubiquity of evolutionary theory in the practice of biology makes it challenging to fully understand or engage in biological investigation without a thorough understanding of evolution. Thus, full participation in biology is hindered by a student's rejection of evolution as a guiding principle of the field. If students are to be well prepared to understand the natural sciences, they should be well educated in evolutionary theory, with attention paid to practices that might mitigate the cognitive barrier of evolution rejection.

Understanding and earnest consideration of evolution is an important goal for non-scientists as well. Evolutionary principles underlie public health issues including vaccinations, antibiotic resistance, and epidemiology; ecological concerns such as invasive species, the biological impacts of climate change, and other environmental implications of human activity; and food security such as pesticide resistance, food crop diversity, and agricultural practices in light of a changing global climate. In addition, science denial by those responsible for guiding public policy may lead to ill-informed decisions and poor potential outcomes regarding future funding for biological sciences. It is for these reasons and more that a general public knowledgeable about evolutionary biology and aware and supportive of its central role in the life sciences is not only desirable, but necessary.

1.1.1 Theoretical background

Knowledge of evolution is perhaps one of the most intuitive factors related to evolution acceptance; multiple studies have found that a significant positive relationship exists between evolution acceptance and evolutionary knowledge (Brown, 2015; Carter et al., 2015; Carter and Wiles, 2014; Deniz et al., 2008; Dorner, 2016; Glaze et al., 2015; Manwaring et al., 2015; Rutledge and Warden, 1999). However, this relationship tends to be weaker than would be expected if knowledge was the only (or even the main) factor affecting acceptance of evolution in US populations. Other authors have found no significant relationship: Sinatra et al. found a significant correlation between acceptance of photosynthesis and photosynthesis knowledge while evolution knowledge and acceptance had no such correlation (Sinatra et al., 2003). Similarly, Cavallo and McCall (2008) found no significant association between evolutionary knowledge and acceptance of evolution, but found that beliefs about the nature of science and evolution acceptance were significantly associated.

An understanding of the nature of science has been much more consistently linked to evolution acceptance, with over three decades of results indicating that understanding the aims, processes, and limitations of scientific knowledge leads to an improved acceptance of evolution

(Akyol et al., 2012; Carter and Wiles, 2014; Cavallo and McCall, 2008; Cofré et al., 2017a; Dorner, 2016; Glaze et al., 2015; Johnson and Peeples, 1987; Lombrozo et al., 2008; Rutledge and Mitchell, 2002; Trani, 2004). Aside from the overwhelming direct evidence, support for the importance of nature of science in evolution acceptance also comes from an overview of creationist arguments against evolution, which often display fundamental misunderstandings of the nature of science (Eldredge, 2000; Matthews, 1997; Pigliucci, 2008).

Beyond direct creationist rhetoric and understandings, religious affiliation and degree of religiosity also have been shown to be related to attitudes towards evolution. While certain denominations outwardly reject evolutionary biology (Resolution on Scientific Creationism, 1982), many are more supportive or accommodating of evolutionary ideas (The Clergy Letter Project, 2004). However, regardless of the official stance of an individual's denomination, there is a greater cultural belief among many that evolution and religion are necessarily in conflict (Meadows et al., 2000). This commonly held dichotomy is often not addressed by biology instructors who do not discuss religious concerns when presenting evolution in their classrooms (Barnes and Brownell, 2016). This might lead to an understanding of religious experience as standing in opposition to scientific exploration and sets up intensity of religious belief (or "religiosity") as a more direct way to test the relationship between religion and evolution acceptance. Many studies have done so, and have found that increased religiosity is associated with decreased acceptance of evolution (Brown, 2015; Carter and Wiles, 2014; Glaze et al., 2015; Heddy and Nadelson, 2013; Lombrozo et al., 2008; Manwaring et al., 2015; Moore et al., 2011; Nadelson and Hardy, 2015; Rissler et al., 2014; Trani, 2004). Religiosity, however, is a complicated construct (Hill and Hood, 1999), referring to both *intrinsic* religiosity (the degree to which religion influences personal understanding and decision making) and *extrinsic* religiosity (the importance of religious worship and religious communities for an individual). For the remainder of this article we will consider only intrinsic religiosity.

Acceptance of evolution is also related to political ideology. People in the United States who identify as Republican or as conservative tend to reject evolution as an explanation for human life on earth at a greater rate than their more centrist and liberal peers (Americans, Politics, and Science Issues, 2015; Newport, 2007). This trend was also found to be significant in studies that used multifactorial models from large survey data (Baker, 2013; Mazur, 2004) and those that looked specifically at acceptance of evolution in university students (Carter and Wiles, 2014; Cotner et al., 2014; Hawley et al., 2011; Nadelson and Hardy, 2015).

A number of various, but related, psychological factors have also been found to be associated with evolution acceptance. Thinking dispositions such as Actively Open-Minded Thinking (openness to ideas that conflict with one's own) have been found to be positively associated with evolution acceptance (Deniz et al., 2008; Sinatra et al., 2003). Sinatra et al. (2003) also found lower levels of epistemological sophistication (expressed as the tendency to rely on authority and view knowledge in absolute terms) to be related to lower levels of evolution acceptance. Finally, other authors have found openness to experience, one of the "Big Five" personality traits that measures intellectualism and creativity (John et al., 2008) to be positively related to acceptance of evolution (Hawley et al., 2011).

A host of other variables, which we will for convenience refer to under the umbrella term of "demographic variables", have been found to be significantly related to acceptance of evolution. Of most relevance to the current study, different researchers have found age (Gallup, 2014; Mazur, 2004), sex and gender (Baker, 2013; Grose and Simpson, 1982; Miller et al., 2006), academic major (Flower, 2006; Ha et al., 2012), geographic location (Mazur, 2004; Miller et al., 2006), rurality (Baker, 2013; Mazur, 2004), youth science exposure (Hawley et al., 2011; Short and Hawley, 2012), interest in science (Ha et al., 2012; Lombrozo et al., 2008), level of biology preparation (Lord and Marino, 1993; Rice et al., 2011), parents' level of education (Hawley et al., 2011), and number of religious friends (Hill, 2014) to be significantly associated with evolution acceptance. Race and/or ethnicity is/are another key demographic variable of interest since in the United States race is an extremely salient factor in educational access and experience (Howard and Navarro, 2016; Ladson-Billinngs and Tate, 1995). Previous research has tended to find no significant relationship between race or ethnicity and evolution acceptance (Dorner, 2016; Nadelson and Hardy, 2015; Woods and Scharmann, 2001), though a recent study finds a significant relationship of ethnicity on acceptance of evolution in one measure of evolution acceptance, but not another (Metzger et al., 2018). Regardless, we feel it is important to include and continue to study, especially in light of Walls' (Walls, 2016, p. 1) challenge for racially inclusive science education: "science education research aimed at improving an individual's science learning and understanding necessarily must take into account the background and experiences that could impact the success of such an undertaking."

Prior work by Dunk and colleagues was among the first studies to combine most of these factors into a single working model (Dunk et al., 2017). In a midwestern public university setting, they found student understanding of the nature of science to be the most significant factor in their model, explaining over 13% of the unique variation in acceptance of evolution. This was followed in explanatory power by religiosity (10%), openness to experience (5%), knowledge of evolution (3%) and religious denomination (3%). Overall, their model explained over 33% of the variation in our measure of acceptance of evolution, which is quite substantial for a model of human cognition and attitudes.

Here, we build upon their work by applying a longitudinal study to measure changes in acceptance of evolution and its associated variables over time. Prior research has often been limited in time, presenting a single snapshot of individuals' acceptance of evolution. However, acceptance of evolution is a construct in flux for many students, attested to by the volumes dedicated to changing acceptance of evolution (via evolution instruction) geared towards instructors (Alters and Alters, 2001; Lynn et al., 2017) or towards the general public (Coyne, 2009; Mayr, 2001; Shermer, 2006). Thus, to better understand the changing nature of evolution acceptance, we conducted the following study to investigate how evolution acceptance and its associated factors may change over time. A longitudinal study allows us to solidify support for our models of evolution acceptance by establishing the associated factors' continuing or changing association with acceptance of evolution. Specifically, through the two approaches we use in this paper we are able to measure: (i) if change in certain variables (e.g., knowledge of evolution, intrinsic religiosity, knowledge of the nature of science, etc.) is associated with change in acceptance of evolution over a year introductory biology; and (ii) if multifactorial models produced show different relationships between the tested variables and acceptance of evolution at different time points throughout the year.

1.1.2 Conceptual framework

To develop a framework to guide our expectations, we relied on the literature cited above as well as two recent reviews of evolution education literature. The first, by Pobiner (2016), provides an extensive background to the current understanding of factors related to evolution acceptance, along with a historical understanding of the problem. Pobiner's work reviews many factors found to be related to evolution acceptance and also adds a historical component to understanding the problem. We build further on that by employing the type of model called for in a recent summary of the field of evolution education authored by over 20 current scholars in the field (Dunk et al., 2019). In this work, Dunk and colleagues advocate for the use of multifactorial models of evolution acceptance employed in a longitudinal fashion to assess changing patterns of evolution acceptance. We take that approach here, and test how evolution acceptance and its change are associated with intrinsic religiosity, openness to experience, understanding of the nature of science, evolutionary misconceptions, evolutionary knowledge, genetic literacy, age, number of college science classes taken, number of college biology classes taken, gender, pre-med status, major, race/ethnicity, geographic area of origin, rurality of childhood home, informal science exposure in youth, interest in science, mother's and father's education level, religious affiliation/denomination, religious activity in daily life, political views generally, political views socially, political views fiscally, political party affiliation, number of religious friends, and number of friends of a similar religion. All of these factors (or similar measures) have been shown to be significantly associated with evolution acceptance in past studies.

1.1.3 Predictions

This study seeks to test two general hypotheses: (i) that when certain variables shown to be related to acceptance of evolution change over time, that change is correlated with change in acceptance of evolution, and (ii) that the amount of variance in acceptance of evolution explained by these variables changes as students progress in knowledge and experience. Specifically, given the previous significant association with evolution acceptance demonstrated by an understanding of the nature of science, religiosity, openness to experience, and measures of knowledge of evolution (Dunk et al., 2017), we expected to find that changes in these variables would be significantly correlated with changes in evolution acceptance. We expected the direction of these relationships to be positive for nature of science understanding, evolution knowledge measures, and openness to experience (individuals who increase in these variables over time will tend to increase in acceptance of evolution) and negative for intrinsic religiosity (individuals who increase in their intrinsic religiosity will tend to decrease in acceptance of evolution).

Due to the large models employed, along with the paucity of research using multifactorial models on many of the measures employed, it was difficult to make highly specific predictions about the changing influence of general groups of variables on evolution acceptance between the beginning and end of a year of university-level introductory biology instruction; however, we had a few general predictions. First, we expected that a year of instruction in biology would tend to diminish the effects of prior preparation on evolution acceptance. We believed that this would be most prominent in variables that measure knowledge of evolution or biology either directly or indirectly, but would also extend to more general demographic variables inasmuch as those variables represent differential access to opportunity to engage with evolutionary biology content. Second, we expected to find that as students learned more about evolutionary biology, they would tend to rely more on scientific explanations of evolution and other biological phenomena and less on non-scientific (e.g., religious) explanations. This would be measured over the year as a decreased association between religious variables and acceptance of evolution, and an increased strength of the relation between variables that show an understanding for how science works to explain the world (that is, those related to understanding of the nature of science) and evolution acceptance. Third, we expected that for some, the year in a university setting would provide students with exposure to new ideas, philosophies, and personalities. Thus, we expected that the levels of an individual's openness to experience would become more useful in explaining evolution acceptance as the year progressed. This would also be reflected in a decreased relation between both political views and political party affiliation with acceptance of evolution, as students who may have been surrounded by more conservative social environments that tend to be less tolerant of evolutionary ideas were exposed to ideas in counterpoint throughout the year of biology instruction and other aspects of the university experience.

1.2 Methods

1.2.1 Data Collection

Introductory biology students (*N* = 656) at a private northeastern university were surveyed under an IRB approved protocol at the beginning and end of a year-long biology course. The introductory biology course is a survey course required for biology majors and majors in related disciplines, but also popular among non-majors for fulfilling general education requirements. The full course is composed of a two-semester (Fall–Spring) sequence, though it is sometimes (rarely) taken out of sequence by some students. Completion of the sequence is not mandatory for all students, but most students take both semesters.

As its primary content resources, the course employs Campbell Biology, the most commonly assigned biology textbook in the United States and possibly world-wide (Online Computer Library Center, 2018; Open Syllabus Project, 2018), as well as its associated Mastering Biology online ancillary package. Furthermore, as many of the students who take this course consider themselves to be pre-medical students, the general biology content guide for the Medical College Admissions Test (Association of American Medical Colleges, 2015) is also used as a reference for determining the scope of topics included in the course sequence. The course sequence thus covers standard content, in large lecture hall and laboratory environments, for introductory biology sequences employing popular textbooks for biology majors and pre-medical students, with coverage of evolution, ecology, anatomy & physiology, cell biology, molecular biology, and the diversity of life. Importantly for the topics of evolution and NOS, additional readings and discussions based on tutorials from the Understanding Evolution and Understanding Science websites of the University of California Museum of Paleontology (Understanding Evolution, 2018; Understanding Science, 2018). Although there are discrete classroom and laboratory lessons on evolution and the nature of science, both are interwoven with other topics throughout the sequence. It should be noted that the instructor does use compatibilist resources such as The Clergy Letter Project (The Clergy Letter Project, 2004) and the works and voices of people representing various religious traditions who have managed to accept evolution while maintaining their religious faith. However, in contrast to studies which seek to investigate the usefulness of a specific curricular intervention, we present here a more naturalistic study with the intent to generalize our results to other introductory biology courses. As such, neither the curriculum nor instruction were altered for the purpose of this study. While our study population, as any, imposes limits on generalizability, we hope that the overview of content is general enough that our results would hold for many different universities' introductory biology courses.

Surveys were administered online through course management software tools (Blackboard) at the beginning of the fall 2016 and end of the spring 2017 semesters (hereafter, “fall” and “spring”). Participation was voluntary, and students received a small amount of extra credit for participation (1 point out of 1,000 per survey instrument). The survey consisted of 6 different instruments, with a 7th survey asking for participants' demographic information, for a total of 171 individual response items. These surveys are summarized in table 1.1.

1.2.2 Survey Measures

Acceptance of evolution, the outcome variable of interest, was measured by the Measure of Acceptance of Evolution (MATE; Rutledge and Sadler, 2007; Rutledge and Warden, 1999). While there are a number of more recent evolutionary acceptance measures (Nadelson and Southerland, 2012; Smith et al., 2016), the MATE was chosen as it is a consistently valid instrument that allows a comparison between the present study and the many former studies that used the measure previously. We are aware of a recent study that finds a potential two-factor structure in the MATE (Romine et al., 2017), and thus investigated the possibility of additional factor structure in the MATE in our population as well. We used the *fa* function from the *psych* package in R with oblimin rotation and the ols factoring method. We found that a three factor structure had the best fit, with the first factor being comprised solely of the positively worded questions and explaining 53% of the variance. We took this to be primarily an artefact of acquiescence in response to the questions and thus we primarily utilized the instrument as a single measure, which is a technique that continues to be endorsed by Romine and colleagues and is recommended by another recent study (Metzger et al., 2018). However, for our linear models (described below), we use both the full measure as well as the first factor in the final model.

Some authors have critiqued the MATE on various grounds (Wagler and Wagler, 2013), most notably that it may include statements that respondents are answering on the basis of knowledge rather than acceptance of evolution (Smith, 2010; Smith et al., 2016). However, we are concerned with maintaining communication with the many studies that have previously used the MATE (over 2 dozen as reported by Romine et al., 2017). We encourage future studies to look into the differences between the MATE, GEANE (Smith et al., 2016), and I-SEA (Nadelson and Southerland, 2012) in both their validity in measuring acceptance of evolution (and only acceptance of evolution) and their performance in associative models.

Another survey instrument that deserves special attention is our measure of an individual's understanding of the aims, processes, and philosophy of science, which are summed up in the term "nature of science". One of the more popular nature of science scales, the Views of Nature of Science questionnaire (Lederman et al., 2002), was not used as the open-ended nature of the questions and the more qualitative data they return were not suitable for this study. Among the other nature of science scales (many of which are summarized in Lederman et al., 1998), we chose the Nature of Scientific Knowledge Survey (NSKS; Rubba and Andersen, 1978), a 48-item, 5-point Likert survey tool. Though it has been some time since its original construction, the NSKS is still being used currently (Ozdemir and Dikici, 2017), and has been successful enough to have been translated into multiple languages since its inception (Chan, 2005; Folmer et al., 2009; Kilic et al., 2005).

The NSKS was considered especially beneficial for this study for its dissection of the nature of science into six distinct factors, each separately measurable within the one instrument. The separate factors are defined as follows (with a brief description of each given parenthetically, paraphrased from Rubba and Andersen, 1978): Amoral (scientific knowledge itself cannot be judged as morally right or wrong, although its methods and applications can), Creative (scientific inquiry is a process that relies on creative input from researchers), Developmental (scientific knowledge is not absolute, and subject to change based on additional evidence), Parsimonious (scientific explanations should be as simple and comprehensive as possible), Testable (scientific explanations are capable of being tested and are open to testing and retesting), and Unified (different branches of scientific inquiry allow for specialization, but all science contributes to a single body of mutually intelligible and relevant knowledge). These distinctly measurable factors allow for a more nuanced analysis of changes in the understanding of science, as well as the relationship between the nature of science and acceptance of evolution. While portions of the class content covered basic scientific reasoning, there was no attempt to specifically discuss or instruct on the nature of science in a philosophical sense. Further, such discussion did not specifically address the numerous different subscales identified by the NSKS.

All survey instruments described in Table 1.1 are 5-item Likert surveys except the factors from the short form of the Evolutionary Attitudes and Literacy Survey (EALS-SF; Short and Hawley, 2012), which are 7-item Likert surveys, and the demographic variables, which vary in form. The demographic questions addressed included gender identity, age, major, race/ethnicity, state or country of origin, rurality of childhood home, childhood informal science exposure, general interest in science, mother's level of education, father's level of education, religious affiliation/ denomination, level of religious activity, political leanings, and political party affiliation. Specific wording for the demographic questions can be found in supplemental table 1.S1.

Survey responses were cleaned by invalidating responses that indicated extremely self-contradictory positions (via comparison of reverse-worded items), which was indication of respondent apathy. Additionally, individuals who were under the age of 18 were excluded from research participation. Gender, major, race/ethnicity, census region of origin, and religious affiliation were all coded. Categories in any variable with less than 3% of total responses were dropped (responses nulled); participants with responses indicated as "other" in codes for religion and political party were also removed, as these were a heterogeneous group with results that would not represent an interpretable pattern.

1.2.3 Analysis- Summary Statistics

Summary statistics for all variables were determined from survey responses from the beginning of the fall semester. These allow a description of the survey population as well as an understanding of the baseline values for each of the variables of interest in the study.

Analysis- Normalized Change Associations

Survey response scores from the beginning of the fall semester and the end of the spring semester (representing a year of introductory biology education) were compared using normalized change (Marx and Cummings, 2007), a metric of change or improvement that attempts to eliminate both ceiling effects and pre-test score bias. Normalized change is similar to normalized gain and runs from -1 (maximal decrease) to +1 (maximal increase). Normalized change uses percentage scores and is calculated as such: if post = pre = 100 or 0, drop; if post = pre ≠ 100 or 0, c = 0; if post < pre, c = (post–pre)/pre; if post > pre, c = (post–pre)/(100–pre). Normalized change scores for measures of evolutionary knowledge, genetic literacy, evolutionary misconceptions, religiosity, openness to experience, and the 7 measures of knowledge of the nature of science (total score and 6 subscores) were each indivudally regressed on the normalized change scores for acceptance of evolution. P-values for these tests were adjusted for multiple comparison using the Holm-Bonferroni sequential procedure (Abdi, 2010).

1.2.4 Analysis- Linear Modeling

To investigate the unique relation between each dependent variable and unadjusted MATE score in both the fall and spring, multifactorial linear models (Huitema, 2011; Rutherford, 2001) were generated for the pre-course and post-course data in a manual stepwise regression fashion. First, individual regressions or one-factor ANOVAs between acceptance of evolution and all other variables in the study were conducted. In total, 15 regressions were conducted (Intrinsic Religiosity, Openness to Experience, NSKS total and all 6 subscales of nature of science conceptions, Evolutionary Misconceptions, Evolutionary Knowledge, Genetic Literacy, age, number of science classes taken in college, number of biology classes taken in college) and 18 one-factor ANOVAs were conducted (gender, pre-med status, major or intended major, race/ ethnicity, census region of origin, rurality of childhood home, childhood exposure to science in informal settings, general interest in science, mother's education level, father's education level, religious affiliation/ denomination, level of religious activity, general political views, political views on social issues, political views on fiscal issues, political party affiliation, number of religious friends, and number of friends with a similar religion to respondent's).

Those variables that had a significant (α=0.05) relationship with acceptance of evolution were included as independent variables into a large multifactorial main effects linear model (the "full model") with MATE score as the dependent variable. Factors in that model that retained a relationship with acceptance of evolution at an alpha of 0.5 or below were included in the next model. This liberal cutoff level was chosen to ensure that all potentially significant variables were included in the final model. The second model (hereafter, "intermediate model") was run similarly to the full model, and again variables with an alpha of 0.5 or below were selected to be included in the "final model". Essentially, iterative models were run until no factors in the model had an alpha above 0.5; this was done with the intent to allow the most power to detect significance levels of the remaining variables in the model. The final model was run as a main effects linear model with acceptance of evolution (as measured by MATE score) as the dependent variable, and the remaining independent variables run as factors (for categorical variables) or covariates (for continuous variables).

This iterative procedure was conducted independently for the data gathered from the beginning of the fall semester and the end of the spring semester. To confirm any differences between the models were due to changes throughout the year and not participant selection, all variables in the fall data set were analyzed for a significant difference between those individuals who went on to the spring semester and those who did not, and all variables in the spring data set were analyzed for a significant difference between those individuals who were enrolled in the fall semester and those who were not. The tests were conducted either as one-factor ANOVAs (for continuous variables) or chi-square tests of independence (for categorical variables). Students who were enrolled in both semesters and students who were enrolled for one semester did not differ for any variables that were included in the main effects linear model after Bonferroni correction for multiple tests.

The main effects models for fall (N=192) and spring (N=252) were compared for differences in the structure of the model as well as differences in the overall and relative effect size of each variable in the model. Multicollinearity in the final models was assessed using generalized variance inflation factors (Fox and Monette, 1992) and was found to be within an acceptable limit (all gVIFs were under 2). Effect size (as eta-squared, η^2; Richardson, 2011) for each variable and P-value adjustments for multiple tests were calculated manually; all other statistical procedures were done in RStudio 1.0.153 (RStudio Team, 2016) running R 3.4.1 (R Core Team, 2017). The final models in both semesters were also separately run with the first factor from our MATE EFA as the dependent variable.

1.3 Results

1.3.1 Descriptive Statistics. Descriptive statistics were calculated for all variables in the fall survey administration. Table 1.2 shows summary statistics for continuous variables, including mean, maximum, minimum, and standard deviation. Frequency tables for select categorical variables are given in table 1.3, and frequency tables for all other variables are given in supplemental table 1.S2.

The student population in this intro biology class tends to be young (M = 18.8, SD = 2.6), with a majority (62%) identifying as white. Women were also in the majority (69%). Over a quarter (26%) of the students in the sample identified with racial or ethnic identities that are considered underrepresented in the natural sciences (Snyder et al., 2016). There is even greater diversity amongst the population studied in political views, religious affiliations, and other demographics such as childhood exposure to informal science learning.

Cronbach's alpha was calculated for the dependent variable, MATE score, and was found to be high (0.9). Looking at levels of evolution acceptance, even upon entering the introductory biology course, students' acceptance of evolution tended to be high (MATE score M = 81.0 SD = 9.7; table 1.4). However, a large number of individuals fell into the moderate category, indicating a substantial potential for change among these students toward higher acceptance of evolution. Students' understanding of the nature of science, evolutionary knowledge, and genetic literacy tended to be more in the middle of the potential range (table 1.2).

1.3.2 Normalized Change. Normalized change scores for acceptance of evolution were found to be significantly correlated with change in almost all tested associated variables (table 1.5)., Figures 1 & 2 show these changes in correlation form; each point is an individual and their normalized change for each variable can be read on the scale from -1 to 1. The correlation was highest between change in the full nature of science understanding measure and change in acceptance of evolution, although two of the NSKS subscales (Parsimonious and Creative) did not significantly change along with acceptance of evolution. The other four NSKS measures showed a fairly robust relationship in their change throughout the year with acceptance of evolution (figure 1.2), with the Testable measure showing the strongest relationship (R^2 = .316, p < .001). The genetic literacy (R^2 = .214, p < .001) and evolutionary knowledge (R^2 = .177, p < .001) factors from the EALS-SF (Short and Hawley, 2012) also showed a significant change with acceptance of evolution. Normalized change scores in the evolutionary misconceptions factor from the EALS-SF, as well as openness to experience and intrinsic religiosity, had a very modest but still significant relationship with change in acceptance of evolution across the year (figure 1.1).

Specifically, we found that a students' change over the semester in their understanding of the nature of science explained 38% of the change in their acceptance of evolution. This finding was highly significant. Change in evolutionary knowledge was significantly positively associated with change in acceptance of evolution as well ($R^2 = 0.17$, p <0.001). Change in openness to experience had a quite modest relationship with change in acceptance of evolution ($R^2 = 0.05$, $p = 0.032$). Finally, change in intrinsic religiosity had a significant, but quite small, negative relationship with change in acceptance of evolution ($R^2 = 0.04$, $p = 0.032$).

1.3.3 Pre-course and post-course linear modeling. Data from survey administrations at the beginning of the fall semester and the end of the spring semester were analyzed separately. Individual variable correlation and ANOVA results, as well as the full and intermediate models for both semesters are given in supplemental tables 1.S3–1.S8. The results of this final model for both semesters are presented in table 1.6, with variables sorted by general category. Eta-squared

(η^2) values are given for comparison both within and between models of each variable's independent contribution to total differences in acceptance of evolution. Overall, significant terms in the early fall model explained 41% of the total variation in acceptance of evolution, while significant terms in the late spring model explained 39% of the total variation in acceptance of evolution. P-values shown in bold on table 1.6 highlight those factors that were significant when the same model was ran with the first factor from our MATE EFA as the dependent variable.

1.4 Discussion

1.4.1 Descriptive Statistics. As noted, the population in our study tends to be young. The majority identify as white, though there is substantial representation from underrepresented racial groups. Women are in the majority. This representation is a common feature of studies that utilize a college undergraduate population, and is very similar to our previous study conducted at a different university (Dunk et al., 2017). Students in this study tended to have a high level of acceptance of evolution at the start of the fall semester, which is also similar to other studies of ours, both at this university (Carter and Wiles, 2014) and elsewhere (Dunk et al., 2017). Although not without precedent in other studies (Dorner and Scott, 2016; Metzger et al., 2018), MATE scores in this study tended to be higher than other studies that utilize the MATE, regardless of age and experience level of respondents (Cavallo and McCall, 2008; Grossman and Fleet, 2017; Rissler et al., 2014; Rutledge and Sadler, 2007; Wiles and Alters, 2011).

With regard to nature of science conceptions as measured by the NSKS, we found that respondents tended on average to score near the midpoint of the instrument scale on the Amoral, Creative, and Parsimonious factors, but averaged somewhat higher on the Developmental, United, and Testable aspects; this indicates a somewhat higher level of understanding of those factors of the nature of science, which were indeed more explicitly engaged during the introductory biology course sequence. Amongst all the factors, it seems that the one least understood by students in this survey was the parsimonious nature of science, as both its mean and its maximum score were the lowest of all the NSKS factors. This is perhaps not surprising, as younger college students tend to view science as complex, and instruction tends to focus on the explanatory power of scientific knowledge, and not its relative simplicity. This pattern of scores, as well as the actual means, closely matches that found by Rubba and Anderson (1978) of non-majors in a biology course in one of the first uses of the NSKS. A somewhat similar pattern is also found in more recent uses of the NSKS (Owens and Foos, 2007), but holds less strongly in international settings (Chan, 2005; Folmer et al., 2009), suggesting the pattern of understanding of the nature of science is not universal and is likely influenced by cultural attitudes and understandings of scientific processes.

1.4.2 Normalized Change. Looking at the correlations between normalized change in acceptance of evolution as well as normalized change in the other continuous variables, the strongest relationship was between an understanding of the nature of science and acceptance of evolution. That is, individuals who increased in their understanding of the nature of science were likely to increase in their acceptance of evolution. This relationship was especially strong and significant for the Amoral, Unified, and Testable subscales of the NSKS. We are unsure why these subscales of understanding the nature of science specifically are correlated with acceptance of evolution, and further research needs to be done to explore this relationship in more detail. However, a link has been shown between young earth creationist beliefs and moral objections to evolution (Short and Hawley, 2012), and so it seems likely that individuals who reduce the level of their view that science is able to make moral claims would increase in their acceptance of evolution. Regardless of the reasons behind these associations, these results suggest that targeting curricular interventions towards these areas of nature of science might be particularly fruitful towards improving understanding of the nature of science and increasing evolution acceptance.

Change in openness to experience, as mentioned above, had a comparatively small relationship with change in acceptance of evolution. Though it was found to be significant, the percent of variance explained was much smaller than that for many of the NSKS and EALS-SF variables, indicating that openness to experience may not be a good target for ways to improve evolution acceptance. This is a relatively surprising finding, given the comparatively strong relationship between openness to experience and acceptance of evolution in a previous cross-sectional survey study (Dunk et al., 2017). It is possible that the current student population differs in their relative importance of the factors related to evolution acceptance when compared to the student population in that study; this is explored in the linear models and discussed below. If the importance of openness differs, it could be manifest in a "ceiling effect" whereby individuals in the current study already have a level of openness that has maximal association with acceptance of evolution, and no increase has a measurable further effect. Alternate explanations are the possibility that the change in openness to experience has a delayed effect on acceptance of evolution, or the possibility that openness to experience only has an effect for larger changes beyond those seen here.

We similarly found changes in intrinsic religiosity to have little relationship with changes in acceptance of evolution. Though the relationship was significant and in the expected direction (with decreasing intrinsic religiosity being associated with increasing acceptance of evolution), less than 4 percent of the variation in change in acceptance of evolution could be explained by changes in intrinsic religiosity. It is important to note this finding does not mean that intrinsic religiosity is not an important factor in acceptance of evolution (see linear models, table 1.6), but rather that *changes in the level* of intrinsic religiosity do not relate strongly to changes in acceptance of evolution. These changes in evolutionary acceptance thus occur mostly independent of religiosity, which is counterintuitive compared to the strong importance of religiosity found in previous cross-sectional studies (Dunk et al., 2017; Glaze et al., 2015). This finding is consistent, however, with the possibility of students reducing their perceived conflict between evolution and religion throughout the semester (Barnes et al., 2017; Truong et al., 2018); reducing the conflict individuals feel between their religion and evolution could increase their acceptance of evolution without changing their religiosity.

Finally, we found that increases in biological knowledge were moderately and significantly associated with increases in evolution acceptance. Specifically, two factors from the short form of the evolutionary attitudes and literacy survey (Short and Hawley, 2012), evolutionary knowledge and genetic literacy, had this strong positive relationship, while a third factor, evolutionary misconceptions, was not significantly related. It is somewhat surprising that observed changes in evolutionary misconceptions are not associated with changes in evolution acceptance. However, the instrument measures only a few, very specific misconceptions; it is possible the student population in the present study has other misconceptions that, if measured, would have a stronger relationship. Further, while we expected changes in both evolutionary knowledge and genetic literacy (as in Miller et al., 2006) to be related to changes in evolution acceptance, we did not expect changes in genetic literacy (knowledge) to have a stronger association. While genetic mechanisms underlie so much evolutionary change, it is possible that the somewhat more indirect nature of knowledge of genetic mechanisms leads to a stronger relationship with acceptance of evolution when compared to evolutionary knowledge. For example, there is reduced opportunity for backfire effects such as belief polarization (see Lewandowsky et al., 2012 for summary), since knowledge of genetics may be less tied to sociopolitical controversy as compared to knowledge of evolution.

1.4.3 Pre-course and post-course linear modeling.

Overall, use of the first factor from our MATE EFA did not lead to substantially different results from using the full MATE tool. Values shown in bold on table 1.6 were significant with either the full MATE or the first factor from the EFA, which explained overall 53% of variance in the MATE. Those factors which are significant with the full tool, but not the reduced factor, tend to be those that have p-values closer to 0.05; thus, it seems likely that those factors no longer being significant is due more to a loss of power with the modified instrument, and not true differences in the patterns of association with the modified dependent variable. Thus, all further discussion will focus on patterns with the full MATE tool used as the dependent variable.

The differences between the models created from the pre-course and post-course survey administrations showed few changes across the year when comparing effect sizes between the fall and spring models. As shown in table 1.6, only variables which were excluded from one or the other models had significantly different eta-squared effect sizes due to the lower CI on significant eta-squared effects approaching, but not reaching, zero. Thus, we interpret this finding to mean that differences between the two models should be viewed with caution, and that overall, there is stability between the two models. This is contrary to our expectations for this analysis– we expected to find that changes in the measured variables seen throughout the year would lead to changes in the strength of association between acceptance of evolution and the tested variables. There are a few changes that we will note here, with the caveat that further analyses should be done to test if these changes are a real effect or due to stochastic sampling effects. Interpretations based on general presence or absence of terms in the models, and not change from fall to spring, are more robust.

Religious affiliation, a very general coding of religious denomination, went from explaining over 8% of variance in early fall (the most of any single term in the model) to being an insignificant model term in spring. In its stead, the number of religious friends an individual reported having (of any religion) went from being an insignificant variable in fall to explaining over 4.7% of the variance in spring. This could signal that these individuals may be shifting in their understanding of the interplay between religion and evolution throughout the year. That is, individuals would start out the year with ideas about the relationship between evolution and religion that is guided mostly by their denomination; however, after a year of interaction with people of different denominations and faiths, it tends to be the case that a more religiously diverse community of friends guides their understanding. The importance of religious friends after a year of biology may also mirror a recent study that found that gains in acceptance of evolution were only significantly associated with in-group identity (Walker et al., 2017). Additionally, portions of the course present science (in general) and evolution (in particular) in a compatibilist fashion with regard to religion, with resources employed (The Clergy Letter Project, 2004) to demonstrate that acceptance of evolution can coincide with traditional religious faith. Similar experiences have been shown to increase students' views of evolution and religion as compatible (Barnes et al., 2017; Truong et al., 2018). Thus, a decreased relationship between religion and acceptance of evolution could occur by an increase in viewing of religion and evolution as compatible (as in Wiles, 2014). We did not measure this possible mediation, as we did not have access to this information at the time of our initial data gathering (fall semester of 2016).

Interestingly, openness to experience did not have a strong enough relationship with acceptance of evolution to be included in either final model in this yearlong study, despite its strong relationship with acceptance of evolution in previously published models (Dunk et al., 2017; Hawley et al., 2011). One possibility is that there was significant overlap between the variance explained by openness to experience and the political variables in the full model, leaving no meaningful variance left for openness to experience to explain after the political variables were included. This is consistent with findings that show openness to experience is highly correlated with political ideology (Van Hiel et al., 2000). It is also possible, as discussed previously, that openness to experience is related to acceptance of evolution only in certain cases or at certain levels not present in our sample.

Political variables explained a large amount of the variation in acceptance of evolution in both the beginning of fall and the end of spring. While this may be unsurprising to many readers, we expected a lesser role for political variables compared to more nuanced psychological variables in the model. Previous research from our lab, using a similar student population (Carter and Wiles, 2014), found that political identity was potent in explaining attitudes towards climate change, but had a smaller role in evolution acceptance. We are unsure if the difference between that previous study and the current one is due to a difference in the measures and model employed or a trend of increasing political polarization in acceptance of evolution, at least among students at the studied university.

When looking at the individual model terms for the political variables, we were surprised to find that two seemingly similar variables explained substantial, independent portions of variance in acceptance of evolution. We are unsure what substantive differences exist between identification as democrat, republican, or independent versus identification of general political views on a scale from conservative to liberal to drive this finding, but it exists and was robust enough to find at both the beginning and end of the year. Further research seeking to understand evolution acceptance should be sure to include both measures of political affiliation, so we can have comparison samples to begin to understand how these variables are related to individuals' acceptance of evolution.

As a group, variables that indicate biological content knowledge did not shift appreciably in their association with evolution acceptance from early fall to late spring– however, one term went from being significant in the beginning of the year to not in the model by the end of the year. The number of biology classes taken in college changed from explaining almost 3% of variation in acceptance of evolution in early fall to no longer being a significant model term in spring. This is in line with our expectation that a year of introductory biology instruction which includes substantial treatment of genetic, evolutionary, and other related content mitigates the relationship between unequal prior college biology instruction and evolution acceptance at the beginning of the fall semester. The (unchanging) relation between genetic literacy and evolution acceptance we found is similar to that recently found in a UK precollege population (Mead et al., 2017), and was also found in an international, multifactorial study of evolution attitudes in the general public (Miller et al., 2006).

At neither time point did evolutionary misconceptions from the EALS-SF have a significant association with an individuals' acceptance of evolution when controlling for other variables. This is in line with the weak relation seen in the linear regression between change in evolutionary misconceptions and change in acceptance of evolution in this study. It is possible that the instrument used did not include enough relevant misconceptions to accurately gauge the relationship between these misunderstandings of evolution and evolution acceptance. However, we think it is also possible that measuring misconceptions is an ineffective way to gauge evolutionary acceptance in general, as students may accept evolution even while retaining misconceptions. Even biology instructors have been found to have a fairly high number of misconceptions about evolution (Nehm and Schonfeld, 2007), and such misconceptions can often be difficult to unseat (Nehm and Reilly, 2007).

We predicted that the effect size of demographic variables would decrease throughout the year, as demographic variables would represent preparation and exposure to evolution, two things that a semester of introductory biology would tend to efface the effects of. Race and ethnicity however, showed no significant change throughout the year. We are somewhat disappointed that the effect of race and ethnicity did not disappear (keeping in mind that differences we may expect to see between racial or ethnic groups, such as those due to differing religious affiliations, were already in the model). One possibility is that race and ethnicity in the current student population is associated with other socioeconomic variables that have a general negative effect on access to education; this is supported by the finding that racial and ethnic identity was not significant in our previous study (Dunk et al., 2017) that used a student population that might be expected to be more equitable with respect to socioeconomic distribution between racial and ethnic identities.

We found that childhood informal science exposure went from being insignificant in fall to explaining 3.5% of the variation in acceptance of evolution in the spring. We would have expected that a variable such as this would be more important in the fall as it seems to measure in some way students' level of preparation. We are unsure why the results are in the opposite direction, but suggest that perhaps the increase, if due to real underlying changes, is due to some change in an unmeasured variable. For example, perhaps individuals with more childhood science exposure were able to take better advantage of the instruction throughout the semester, and thus this exposure is not important so much in itself but in the way it allowed students to receive new information.

Finally, we look at the nature of science variables. Here, we exhibit the most caution with regards to stochasticity causing differences between inclusion of model terms. An understanding of the nature of science as unified was significant and showed no significant change in strength of relationship with evolution acceptance throughout the year. However, an understanding of science as amoral was only important in the early fall and was not included in the spring model (due to insignificance in the previous step's "full model"). Likewise, an understanding of science as a process that is composed of, and requires, testable predictions was not eligible to be included in the model at the beginning of the year, but was very significant by the end of the year, explaining 4.4% of the variation in acceptance of evolution.

We did not have specific predictions about how the importance of the individual components of the NSKS may change throughout the year, but it may be that this change demonstrates a move from a naïve to a more mature understanding of the nature of science and evolutionary biology. That is, some individuals at the start of the year are influenced by their prior conceptions that science has a moral component and can make statements that compete in that arena. This would be especially problematic for religious students who rely on their religion as a moral guide if they feel that science is presented as a suggested replacement for this aspect of their faith. Such a problem may lead to such students to feel uncomfortable in a biology classroom, which can lead to disengagement (Barnes et al., 2017). In contrast, an understanding of the testable nature of science leads to an understanding of the distinction between science and other forms of knowing– an understanding that scientific claims require testable hypotheses and that matters of religious faith are not investigated by science due to this distinction. The testable nature of science (under the similar understanding of tentativeness) has often been associated with increased evolution acceptance (e.g., Borgerding et al., 2017).

In the past five years, researchers of evolution education have found that individual relationships exist between acceptance of evolution and the general groups of factors such as knowledge variables (Carter and Wiles, 2014; Cofré et al., 2017a; Mead et al., 2017), political variables (Cotner et al., 2014), nature of science variables (Carter and Wiles, 2014; Cofré et al., 2017a, 2017b), and religious variables (Carter and Wiles, 2014), which are all general categories of variables we found significant in our analysis as well. In addition, many recent authors have found that psychological measures such as need for cognition (Kurdna et al., 2015) and epistemological types (Borgerding et al., 2017) are related to acceptance of evolution; we did not find a relation between acceptance of evolution and our psychological measure, openness to experience.

Comparing our study to multifactorial studies published within the past five years as well as another recent and well cited paper places our findings in even better context. When accounting for other variables, our study and others have found evolution acceptance to be significantly associated with knowledge of evolution (Dorner, 2016; Dunk et al., 2017; Glaze et al., 2015; Mead et al., 2017; Weisberg et al., 2018), genetic knowledge (Mead et al., 2017; Miller et al., 2006), political variables (Miller et al., 2006; Walker et al., 2017; Weisberg et al., 2018), nature of science variables (Dorner, 2016; Dunk et al., 2017; Glaze et al., 2015), and religious variables (Dunk et al., 2017; Glaze et al., 2015; Miller et al., 2006; Rissler et al., 2014; Weisberg et al., 2018), as well as demographic variables such as race/ethnicity (Walker et al., 2017). However, differences exist as well. Others have found evolution acceptance to be associated with age (Miller et al., 2006; Weisberg et al., 2018) and gender (Miller et al., 2006), but our model (as well as a previous one by us; Dunk et al., 2017) found no association with either of these. Further, other studies find a relation between evolution acceptance and general educational attainment (Miller et al., 2006; Rissler et al., 2014; Walker et al., 2017; Weisberg et al., 2018), which we did not test directly; our closest proxy was number of college biology courses taken, which we found to be important in the beginning of the year, but not the end of the year.

Finally, the overall similarity between the models produced from students surveyed at the beginning of fall and the end of spring show that there may be overall few changes in the relationship between the associated variables and acceptance of evolution. This lends support to the idea that analyses of this sort from across different time points of the undergraduate student experience may be directly comparable.

1.5 Limitations

While the findings in this report are supported by robust statistical evidence, all studies are only as applicable as their study population. With that in mind, we acknowledge that these findings are from an undergraduate student population, which is further limited by a plurality of students being white and female. We further acknowledge the limitation of conducting the study at a private northeastern university; although many of our results are supported by previous work of ours at a public midwestern university and more generally in the literature, we encourage others to conduct similar studies in diverse academic settings and would be open to collaborations to do so. We also acknowledge the limitation of using only students in introductory biology. We are currently conducting a study that will explore similar questions using a more general student population. We would encourage others to do the same, as well as to explore the differences between novice and experienced biology students. We would also like to address the notion of causality in our study. It should be noted that none of the relationships described above meet a strict notion of causality; our goal with this study, which we think we have accomplished, was to show important associations between variables, but the causality of that relationship is not tested. It is possible some causal language has made its way into our descriptions, and we apologize if that is the case; nonetheless, our results do show significant interactions between the variables discussed and acceptance of evolution. We feel that the results of significant correlations between change in acceptance of evolution and change in other variables sets a strong case for the potential that the associated variables do indeed cause a change; however, we acknowledge that further studies need to be done to establish directional causality, and we enthusiastically encourage such efforts. Lastly, we acknowledge the limitation of using only quantitative models to explore student perceptions and attitudes; however, many of the general trends we find to be important in evolution acceptance were also found in a previous qualitative study of ours (Wiles, 2014).

1.6 Conclusions

We undertook this study to improve upon previous studies, but also to set a new baseline for further explorations of acceptance of evolution, especially in a longitudinal format. This baseline will allow further research of ours and others to explore the similarities and differences between different groups in acceptance of evolution (such as between students at different types of institutions, and ideally, between undergraduate students and different segments of the general population). Longitudinal explorations such as this study have been called for by many leaders in the evolution education community (Dunk et al., 2019), and this work represents a first step toward moving the field in the directions they advise.

Our data show that all general groups of variables we defined (political, religious, nature of science, knowledge, and demographic) make a substantial contribution to explaining the variance in evolution acceptance, with little change throughout a year of introductory biology instruction. Further, these variables are similar to those found important in many of the studies of evolution education and acceptance conducted in the past five years in a variety of settings. In addition, we have shown that when these variables associated in linear models with evolution acceptance change throughout the year, acceptance of evolution changes as well. Looking specifically at changes across the year, we found that changes in understanding the nature of science, genetic literacy, and evolutionary knowledge were strongly and significantly correlated with changes in evolution acceptance, indicating that these could all be very fruitful potential targets for interventions designed to increase the acceptance of evolution.

1.7 Tables and Figures

Table 1.1. Surveys used the current study.

Survey Coverage	**Survey Name**	**Citation**
Acceptance of Evolution	Measure of Acceptance of the Theory of Evolution (MATE)	Rutledge and Sadler, 2007
Knowledge of the Nature of Science	Nature of Scientific Knowledge Survey (NSKS)	Rubba and Andersen, 1978
Religiosity	Combined version of the Duke University Religion Index (DUREL) and Hoge's Intrinsic Religious Motivation Scale	Hoge, 1972; Koenig and Büssing, 2010
Epistemological Sophistication	Openness to Experience factor of Big Five Inventory	John et al., 2008
Evolution Knowledge	Genetic Literacy, Evolutionary Knowledge, and Evolutionary Misconceptions factors from Evolutionary Attitudes and Literacy Survey- Short Form (EALS-SF)	Short and Hawley, 2012
Friend Network	Edited portion of National Study of Youth and Religion	Hill, 2014
Demographics	Various studies	

Table 1.2. Summary statistics for continuous variables in the fall survey administration.

	Mean	**SD**	**Minimum (Min Possible)**	**Maximum (Max Possible)**
MATE	81.00	9.66	32 (20)	100 (100)
Intrinsic Religiosity	23.88	8.30	10 (10)	50 (50)
Openness to Experience	35.86	5.90	19 (10)	49 (50)
NSKS Total	171.68	12.24	133 (48)	216 (240)
NSKS Amoral	26.92	4.18	16 (8)	38 (40)
NSKS Creative	27.46	4.84	8 (8)	40 (40)
NSKS Developmental	30.39	3.19	20 (8)	40 (40)
NSKS Parsimonious	22.96	3.23	14 (8)	35 (40)
NSKS Testable	31.85	3.85	19 (8)	40 (40)
NSKS Unified	31.94	3.43	20 (8)	40 (40)
Evolutionary Misconceptions	12.54	3.26	3 (3)	21 (21)
Evolutionary Knowledge	26.98	3.69	16 (5)	35 (35)
Genetic Literacy	19.97	3.60	11 (4)	28 (28)
Age	18.81	2.62	18 (18)	64 (∞)
No. College Science Classes	1.56	2.06	0 (0)	20 (∞)
No. College Biology Classes	0.25	0.66	0 (0)	7 (∞)
Parents' Combined Education Level	6.39	1.40	2 (0)	8 (8)

Table 1.3. Frequency tables for select categorical variables in the fall survey administration.

Variable	**Category**	**Number[1]**	**Percent**
Gender			
	Female	362	69.2
	Male	158	30.2
	Other Gender Identities	3	0.6
Major			
	Applied Health Majors	130	25.0
	Biology	164	31.5
	Business	10	1.9
	Communications	12	2.3
	Education	12	2.3
	Humanities	29	5.6
	Math and Engineering	16	3.1
	Physical Sciences	18	3.5
	Social Sciences	67	12.9
	Multiple	17	3.3
	Other	2	0.4
	Undecided	43	8.3
Race/Ethnicity			
	American Indian or Alaska Native	5	1.0
	Asian	58	11.0
	Black	42	8.0
	Hispanic	66	12.6
	Native Hawaiian or Pacific Islander	1	0.2
	White	327	62.3
	Multiracial	26	5.0
Rurality of Childhood Home			
	Rural	68	13.0
	Suburban	323	61.8
	Urban	132	25.2
Childhood Informal Science Exposure			
	Almost Never	16	3.1
	Rarely	71	13.5
	Somewhat Rarely	117	22.3
	Somewhat Often	233	44.5
	Very Often	87	16.6
Religious Affiliation			
	Baptist	7	1.4
	Catholic	185	36.6
	Episcopalian	2	0.4
	Evangelical	16	3.2
	Lutheran	3	0.6
	Methodist	1	0.2

	Non-denominational Christian	51	10.1
	Orthodox	3	0.6
	Pentecostal	2	0.4
	Presbyterian	1	0.2
	Protestant	16	3.2
	Unitarian Universalist	1	0.2
	All Christian	*288*	*56.9*
	Buddhist	9	1.8
	Hindu	5	1.0
	Jewish	45	8.9
	Muslim	9	1.8
	Pagan	1	0.2
	Nonreligious	103	20.4
	Spiritual but not Religious	46	9.1
Religious Activity			
	Not Active	149	28.5
	Not Very Active	126	24.1
	Somewhat Active	133	25.4
	Very Active	36	6.9
	Does Not Apply	79	15.1
General Political Views			
	Strongly Conservative	13	2.5
	Somewhat Conservative	60	11.5
	Moderate/ Middle of the Road	208	39.9
	Somewhat Liberal	163	31.3
	Strongly Liberal	77	14.8
Political Party			
	Strong Republican	22	4.2
	Not-so-strong Republican	39	7.5
	Independent-leaning Republican	42	8.0
	Independent	71	13.6
	Independent-leaning Democrat	97	18.6
	Not-so-strong Democrat	70	13.4
	Strong Democrat	62	11.9
	Other	14	2.7
	Don’t Know	105	20.1
Number of Religious Friends			
	0	91	17.8
	1	113	22.1
	2	138	27.0
	3	72	14.1
	4	51	10.0
	5	47	9.2

[1]Numbers in each category may not add to the same total due to nonresponse. Nonresponses are not included.

Table 1.4. Levels of evolution acceptance for introductory biology students at the beginning of the fall semester.

Acceptance level[1]	**Score range**	**Number of respondents**
Very low	20-52	4
Low	53-64	17
Moderate	65-76	118
High	77-88	237
Very high	89-100	108

[1]Score range for acceptance levels defined by Rutledge and Sadler (2007).

Table 1.5. Results of correlations between normalized change of acceptance of evolution (MATE score) and normalized change of 12 different independent variables.

Variable	R^2	p_{adj}†
Nature of Science Understanding (NSKS)	.378	< .000 001
NSKS Testable	.316	< .000 001
NSKS Unified	.294	< .000 001
NSKS Amoral	.244	< .000 001
NSKS Developmental	.082	.009
NSKS Parsimonious	.019	NS
NSKS Creative	.018	NS
Genetic Literacy (EALS-SF)	.214	< .000 001
Evolutionary Knowledge (EALS-SF)	.177	< .000 001
Evolutionary Misconceptions (EALS-SF)	.040	.025
Openness to Experience	.049	.032
Intrinsic Religiosity	.038	.032

†Adjusted *p* values are corrected by Holm-Bonferroni method.

Table 1.6. Final general linear models for both the early fall and late spring of a year of introductory biology. Acceptance of evolution (as measured by the MATE) is the dependent variable. Variables that remained significant in model with shorter MATE measure (determined by EFA) as dependent variable have their p-values shown in **bold**. Eta-squared values in **bold** indicate non-overlap between the two models. (NIFM = not in final model)

Early Fall				Late Spring		
			Political Variables			
F	***p***	η^2		***F***	***p***	η^2
3.21	**0.003**	.0714	Political Party	2.12	0.043	.0411
3.87	**0.005**	.0492	General Political Views	4.01	**0.004**	.0444
	Combined $\eta^{2:}$	.1206			*Combined* $\eta^{2:}$	.0855
			Religious Variables			
F	***p***	η^2		***F***	***p***	η^2
4.63	**<0.001**	**.0882**	Religious Affiliation	1.48	0.177	
4.00	0.047	.0127	Intrinsic Religiosity	9.01	**0.003**	.0249
1.15	0.336		Number of Religious Friends	3.43	0.006	**.0474**
NIFM			Religious Activity	1.04	0.390	
	Combined $\eta^{2:}$	.1009			*Combined* $\eta^{2:}$	.0723
			Nature of Science Variables			
F	***p***	η^2		***F***	***p***	η^2
7.06	**0.009**	**.0224**	NSKS Amoral	NIFM		
7.04	**0.009**	.0223	NSKS Unified	15.95	**<0.001**	.0441
1.48	0.226		NSKS Testable	15.84	**<0.001**	**.0438**
NIFM			NSKS Parsimonious	0.78	0.379	
	Combined $\eta^{2:}$	.0447			*Combined* $\eta^{2:}$	.0879
			Knowledge Variables			
F	***p***	η^2		***F***	***p***	η^2
10.66	**0.001**	.0338	Evolutionary Knowledge	15.28	**<0.001**	.0423
9.93	**0.002**	**.0315**	Number of College Biology Classes Taken	NIFM		
4.37	0.038	.0139	Genetic Literacy	11.34	**<0.001**	.0314
NIFM			Evolutionary Misconceptions	0.54	0.464	
	Combined $\eta^{2:}$	.0792			*Combined* $\eta^{2:}$	.0737
			Demographic Variables			
F	***p***	η^2		***F***	***p***	η^2
4.71	**0.001**	.0598	Race/Ethnicity	3.20	0.014	.0354
NIFM			Childhood Informal Science Exposure	3.18	**0.015**	**.0351**
2.23	0.111		Rurality	NIFM		
	Combined $\eta^{2:}$	.0598			*Combined* $\eta^{2:}$	.0705

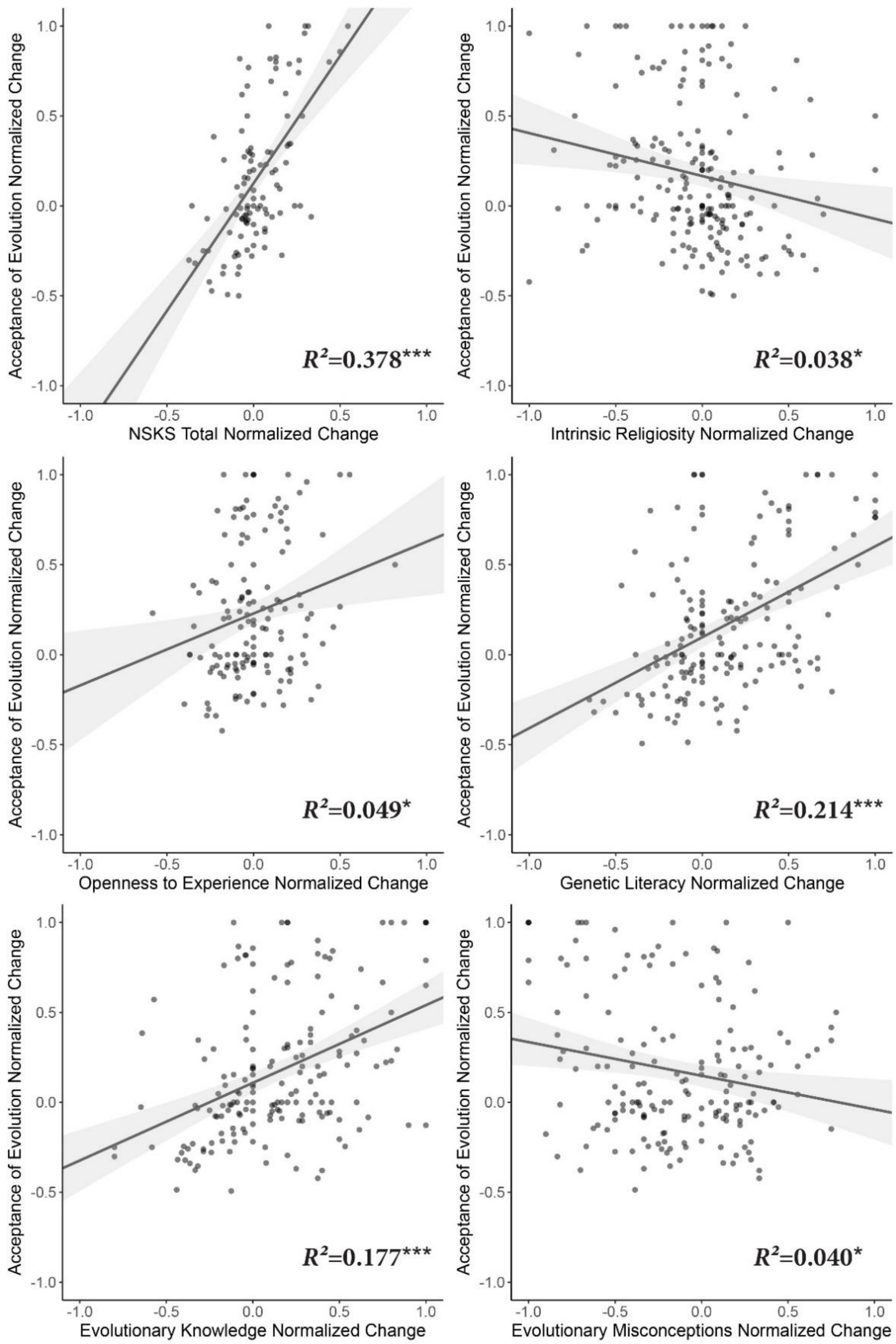

Figure 1.1. Correlations between normalized change in acceptance of evolution and normalized change in 6 different variables. R^2 values are given on each plot, and shading represents 95% CI of the regression line. Dots are translucent, so darkened areas show overlap of multiple points. Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, [NS] = Not Significant.

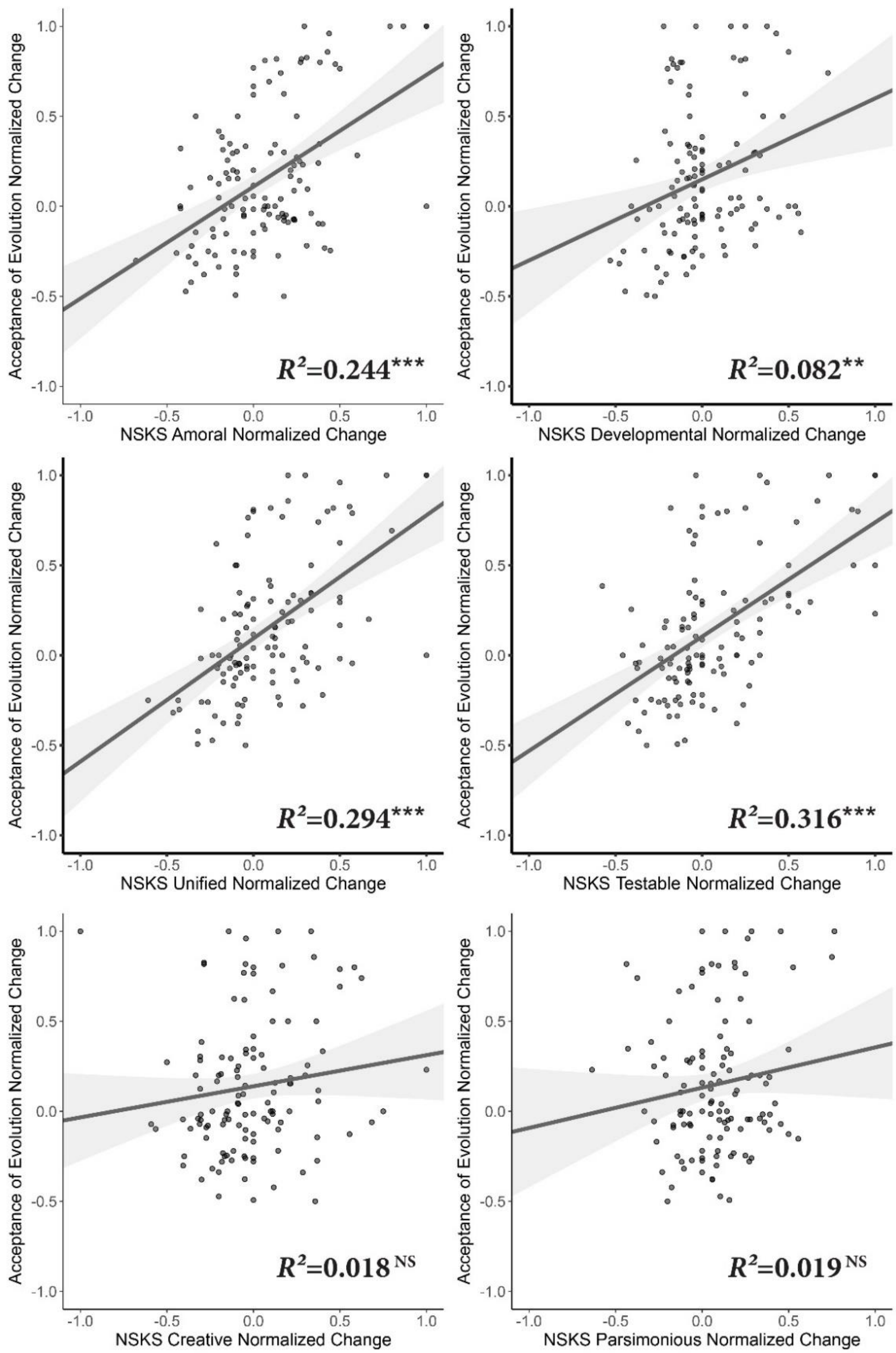

Figure 1.2. Correlations between normalized change in acceptance of evolution and normalized change in the nature of science variables measured by the NSKS. R^2 values are given on each plot, and shading represents 95% CI of the regression line. Dots are translucent so darkened areas show overlap of multiple points. Significance: * = p <0.05, ** = p < 0.01, *** = p < 0.001, ^{NS} = Not Significant.

1.8 Supplement

Table 1.S1. Question wording of demographic variables.

1. What is your gender identity?
Free Response
2. What is your current age (in years)?
Free Response
3. Do you consider yourself to be "Pre-med"?
A. Yes B. No
4. What is your major or intended major? (NOTE: Pre-med is not a major)
Free Response
5. Which of the following best describe you? Select all that apply.
A. American Indian or Alaska Native B. Asian C. Black or African American D. Hispanic or Latino E. White F. Other
6. If you selected "Other" in the previous question please state your race/ethnicity in the text box here.
Free Response
7. If you are from the United States, please type the state or territory you are from. If you are not from the United States, please type the country you are from.
Free Response
8. Which term best describes where you grew up?
A. Urban B. Suburban C. Rural
9. Growing up, how often were you exposed to science outside of school (e.g., by visiting museums, science centers, etc.)?
A. Almost Never B. Rarely C. Somewhat Rarely D. Somewhat Often E. Very Often
10. How would you rank your interest in science in general?
A. Not at all interested B. Mostly Uninterested C. Neutral D. Somewhat interested E. Very Interested
11. How many science classes have you taken in college (excluding this one)?
Free Response
12. How many biology classes have you taken in college (excluding this one)?
Free Response
13. What is your mother's highest level of education?
A. Never attended school or only attended kindergarten *B. Grades 1 through 8 (Elementary)* *C. Grades 9 through 11 (Some high school)* *D. Grade 12 or GED (High school graduate)* *E. Attended college but did not graduate* *F. Associate's or technical degree* *G. College graduate (Bachelor's degree)* *H. Post-bachelor's degree (Graduate school, Law school, Medical school)*
14. What is your father's highest level of education?
A. Never attended school or only attended kindergarten

B. Grades 1 through 8 (Elementary) *C. Grades 9 through 11 (Some high school)* *D. Grade 12 or GED (High school graduate)* *E. Attended college but did not graduate* *F. Associate's or technical degree* *G. College graduate (Bachelor's degree)* *H. Post-bachelor's degree (Graduate school, Law school, Medical school)*
15. What, if any, is your religious affiliation?
A. Agnostic B. Atheist C. Buddhist D. Catholic E. Evangelical Christian *F. Hindu G. Jewish H. Mainline Protestant I. Muslim* *J. Non-denominational Christian K. Spiritual but not religious L. Other*
16. If you answered "Other" in the previous question, please use this text box to type in your religious denomination. You may also use this space to clarify or add detail to your response regardless of your choice above.
Free Response
17. How active do you consider yourself to be in the practice of your religious preference?
A. Not active B. Not very active C. Somewhat active *D. Very active E. Does not apply*
18. In general, how would you describe your political views?
A. Strongly liberal B. Somewhat liberal C. Moderate/ Middle of the road *D. Somewhat conservative E. Strongly conservative*
19. Politically, what are your views on most social issues (e.g., immigration, capital punishment, or marriage equality):
A. Strongly liberal B. Somewhat liberal C. Moderate/ Middle of the road *D. Somewhat conservative E. Strongly conservative*
20. Politically, what are your views on most fiscal issues (e.g., government spending, trade regulation, or economic regulation):
A. Strongly liberal B. Somewhat liberal C. Moderate/ Middle of the road *D. Somewhat conservative E. Strongly conservative*
21. Generally speaking, do you consider yourself to be a(n):
A. Strong Democrat B. Not-so-strong Democrat *C. Independent-leaning Democrat D. Independent* *E. Independent-leaning Republican F. Not-so-strong Republican* *G. Strong Republican H. Other (see next question) I. Don't Know*
22. If you answered "Other" to the previous question please use the text box here to type your political party affiliation. If you made a selection in the previous question please leave this blank.
Free Response

Table 1.S2. Frequency tables for categorical variables not presented in the main text. Data is from fall survey administration.*

Variable	Category	Number[1]	Percent
Pre-Med Student			
	Yes	181	34.4
	No	345	65.6
Census Region			
	International	35	6.9
	Midwest	21	4.1
	Northeast	351	69.2
	South	44	8.7
	West	44	8.7
	Puerto Rico	4	0.8
	Other	8	1.6
Science Interest			
	Not at all interested	7	1.3
	Mostly uninterested	33	6.3
	Neutral	70	13.4
	Somewhat interested	165	31.7
	Very interested	246	47.2
Mother's Education Level			
	Never attended school or only attended kindergarten	0	0.0
	Grades 1 through 8 (Elementary)	5	1.0
	Grades 9 through 11 (Some high school)	12	2.3
	Grade 12 or GED (High school graduate)	85	16.3
	Attended college but did not graduate	38	7.3
	Associate's or technical degree	49	9.4
	College graduate (Bachelor's degree)	174	33.3
	Post-bachelor's degree (Graduate school, law school, medical school)	154	29.4
	Does not apply	6	1.1
Father's Education Level			
	Never attended school or only attended kindergarten	1	0.2
	Grades 1 through 8 (Elementary)	9	1.7

	Grades 9 through 11 (Some high school)	15	2.9
	Grade 12 or GED (High school graduate)	88	16.8
	Attended college but did not graduate	36	6.9
	Associate's or technical degree	45	8.6
	College graduate (Bachelor's degree)	146	27.9
	Post-bachelor's degree (Graduate school, law school, medical school)	162	31.0
	Does not apply	21	4.0
Social Political Views			
	Strongly Conservative	12	2.3
	Somewhat Conservative	45	8.7
	Moderate/ Middle of the Road	162	31.2
	Somewhat Liberal	161	31.0
	Strongly Liberal	140	26.9
Fiscal Political Views			
	Strongly Conservative	31	6.0
	Somewhat Conservative	98	18.8
	Moderate/ Middle of the Road	241	46.3
	Somewhat Liberal	112	21.5
	Strongly Liberal	39	7.5
Number of Similarly Religious Friends			
	0	52	10.2
	1	58	11.3
	2	102	19.9
	3	122	23.8
	4	92	18.0
	5	86	16.8

*See table 1.3 in main text for the remaining categorical variables.
[1]Numbers in each category may not add to the same total due to nonresponse. Nonresponses are not included.

Table 1.S3. Results of individual correlations or ANOVAs of given variables on MATE score in fall semester.

Variable	R^2	***p***
Intrinsic Religiosity	0.1778	<.000 001
Openness to Experience	0.0109	.0487
NSKS Total	0.1231	<.000 001
NSKS Amoral	0.1152	<.000 001
NSKS Creative	0.0000	.9193
NSKS Development	0.0215	.0126
NSKS Parsimonious	0.0008	.6376
NSKS Testable	0.0877	<.000 001
NSKS Unified	0.1029	<.000 001
Evolutionary Misconceptions	0.0073	.0046
Evolutionary Knowledge	0.1372	<.000 001
Genetic Literacy	0.1007	<.000 001
Age	0.0054	0.1175
No. College Science Classes	0.0008	0.5383
No. College Biology Classes	0.0431	.000 008
Variable	***F* statistic (df)**	***p***
Gender	0.09 (1, 452)	0.7609
Pre-Med	0.08 (1, 458)	0.7749
Major	1.35 (9, 436)	0.2093
Race/Ethnicity	5.26 (4, 450)	0.0004
Census Region	0.80 (5, 460)	0.5507
Rurality	4.10 (2, 454)	0.0173
Childhood Informal Science Exposure	3.59 (4, 454)	0.0068
Science Interest	5.65 (3, 445)	0.0008
Mother’s Education Level	1.39 (5, 444)	0.2269
Father’s Education Level	1.32 (6, 445)	0.2460
Religious Affiliation	9.02 (6, 400)	<.000 001
Religious Activity	13.53 (4, 454)	<.000 001
General Political Views	6.80 (4, 452)	0.000 026
Social Political Views	9.57 (4, 451)	<.000 001
Fiscal Political Views	2.70 (4, 452)	0.0301
Political Party	4.26 (7, 440)	0.0001
Number of Religious Friends	4.66 (5, 455)	0.0004
Number of Similarly Religious Friends	0.97 (5, 455)	0.4331

Table 1.S4. Results of “full model” GLM of given variables on MATE score in fall semester.

Dependent Variable	***F* statistic (df)**	***p***
Intrinsic Religiosity	1.05 (1, 106)	0.3068
Openness to Experience	0.05 (1, 106)	0.8147
NSKS Amoral	5.33 (1, 106)	0.0229
NSKS Developmental	1.34 (1, 106)	0.2497
NSKS Testable	1.27 (1, 106)	0.2632
NSKS Unified	4.58 (1, 106)	0.0347
Evolutionary Misconceptions	0.28 (1, 106)	0.5919
Evolutionary Knowledge	12.03 (1, 106)	0.0008
Genetic Literacy	0.08 (1, 106)	0.7707
No. College Biology Classes	12.70 (1, 106)	0.0005
Race/Ethnicity	2.46 (4, 106)	0.0498
Rurality	2.32 (2, 106)	0.1028
Childhood Informal Science Exposure	0.89 (4, 106)	0.4736
Science Interest	0.21 (3, 106)	0.8861
Religious Affiliation	4.08 (6, 106)	0.0010
Religious Activity	1.11 (4, 106)	0.3542
General Political Views	2.75 (4, 106)	0.0320
Social Political Views	0.61 (4, 106)	0.6531
Fiscal Political Views	0.47 (4, 106)	0.7578
Political Party	3.53 (7, 106)	0.0019
Number of Religious Friends	1.28 (5, 106)	0.2763

Table 1.S5. Results of “intermediate model” GLM of given variables on MATE score in fall semester.

Dependent Variable	***F* statistic (df)**	***p***
Intrinsic Religiosity	2.09 (1, 144)	0.1507
NSKS Amoral	6.89 (1, 144)	0.0096
NSKS Developmental	0.30 (1, 144)	0.5818
NSKS Testable	1.20 (1, 144)	0.2758
NSKS Unified	5.69 (1, 144)	0.0130
Evolutionary Knowledge	10.30 (1, 144)	0.0016
Genetic Literacy	3.13 (1, 144)	0.0789
No. College Biology Classes	8.91 (1, 144)	0.0033
Race/Ethnicity	3.83 (4, 144)	0.0055
Rurality	2.20 (2, 144)	0.1143
Childhood Informal Science Exposure	0.82 (4, 144)	0.5140
Religious Affiliation	3.84 (6, 144)	0.0014
Religious Activity	0.54 (4, 144)	0.7041
General Political Views	3.72 (4, 144)	0.0065
Political Party	3.38 (7, 144)	0.0023
Number of Religious Friends	1.01 (5, 144)	0.4161

Table 1.S6. Results of individual correlations or ANOVAs of given variables on MATE score in spring semester.

Variable	R^2	***p***
Intrinsic Religiosity	0.1668	<.000 001
Openness to Experience	0.0459	0.0002
NSKS Total	0.4096	<.000 001
NSKS Amoral	0.1537	<.000 001
NSKS Creative	0.0262	0.0062
NSKS Development	0.2942	<.000 001
NSKS Parsimonious	0.0321	0.0024
NSKS Testable	0.3293	<.000 001
NSKS Unified	0.4216	<.000 001
Evolutionary Misconceptions	0.0539	0.000 024
Evolutionary Knowledge	0.3939	<.000 001
Genetic Literacy	0.3702	<.000 001
Age	0.0024	0.3844
No. College Science Classes	0.0003	0.7694
No. College Biology Classes	0.0048	0.2231
Variable	***F* statistic (df)**	***p***
Gender	0.20 (1, 309)	0.6539
Pre Med	0.62 (1, 311)	0.4308
Major	0.98 (7, 289)	0.4439
Race/Ethnicity	5.77 (4, 300)	0.0002
Region	1.58 (4, 290)	0.1791
Rurality	5.33 (2, 309)	0.0053
Childhood Informal Science Exposure	3.90 (4, 306)	0.0042
Science Interest	5.52 (4, 307)	0.0003
Mother’s Education Level	0.62 (4, 293)	0.6472
Father’s Education Level	0.79 (6, 302)	0.5767
Religious Affiliation	5.11 (7, 275)	0.000 018
Religious Activity	5.36 (4, 307)	0.0004
Political General	4.79 (4, 306)	0.0009
Political Social	6.86 (4, 305)	0.000 027
Political Fiscal	2.42 (4, 304)	0.0488
Political Party	3.48 (7, 292)	0.0013
Number of Religious Friends	5.75 (5, 306)	0.000 044
Number of Similarly Religious Friends	0.63 (5, 306)	0.6782

Table 1.S7. Results of "full model" GLM of given variables on MATE score in spring semester.

Dependent Variable	***F* statistic (df)**	***p***
Intrinsic Religiosity	10.87 (1, 140)	0.0012
Openness to Experience	0.18 (1, 140)	0.6693
NSKS Amoral	0.05 (1, 140)	0.8197
NSKS Creative	0.51 (1, 140)	0.4757
NSKS Developmental	0.11 (1, 140)	0.7387
NSKS Parsimonious	0.88 (1, 140)	0.3485
NSKS Testable	12.98 (1, 140)	0.0004
NSKS Unified	12.49 (1, 140)	0.0006
Evolutionary Misconceptions	1.37 (1, 140)	0.2444
Evolutionary Knowledge	17.29 (1, 140)	0.000 056
Genetic Literacy	5.98 (1, 140)	0.0157
Race/Ethnicity	3.78 (4, 140)	0.0059
Rurality	0.01 (2, 140)	0.9855
Childhood Informal Science Exposure	2.53 (4, 140)	0.0431
Science Interest	0.50 (4, 140)	0.7372
Religious Affiliation	1.63 (7, 140)	0.1316
Religious Activity	1.10 (4, 140)	0.3602
Political General	3.65 (4, 140)	0.0074
Political Social	0.22 (4, 140)	0.9292
Political Fiscal	0.64 (4, 140)	0.6354
Political Party	2.39 (7, 140)	0.0242
Number of Religious Friends	3.24 (5, 140)	0.0085

Table 1.S8. Results of "intermediate model" GLM of given variables on MATE score in spring semester.

Dependent Variable	***F* statistic (df)**	***p***
Intrinsic Religiosity	8.68 (1, 176)	0.0037
NSKS Creative	0.24 (1, 176)	0.6218
NSKS Parsimonious	0.64 (1, 176)	0.4244
NSKS Testable	15.53 (1, 176)	0.0001
NSKS Unified	16.32 (1, 176)	0.000 080
Evolutionary Misconceptions	0.72 (1, 176)	0.3957
Evolutionary Knowledge	15.09 (1, 176)	0.0001
Genetic Literacy	11.55 (1, 176)	0.0008
Race/Ethnicity	3.30 (4, 176)	0.0123
Childhood Informal Science Exposure	3.40 (4, 176)	0.0105
Religious Affiliation	1.30 (7, 176)	0.2552
Religious Activity	1.08 (4, 176)	0.3665
General Political Views	4.32 (4, 176)	0.0023
Political Party	2.24 (7, 176)	0.0334
Number of Religious Friends	2.99 (5, 176)	0.0129

Chapter 2. Yearlong changes in evolution acceptance in a general student cohort

2.1 Introduction

Evolutionary biology is a fundamental concept in science, underlying our understanding of nearly all biological phenomena (Dobzhansky, 1973). However, evolution is a scientific topic that remains socially controversial despite its near-universal adoption in science (Graffin, 2003). For most scientific topics, the distinction between understanding and accepting a phenomenon is essentially null. However, evolution, climate change, and vaccination are all topics which are well-supported and accepted by scientists, but viewed with some level of skepticism by the general public.

The reasons for rejection of evolutionary theory are no doubt personal. However, there is a body of literature which helps us to understand the most common reasons that individuals choose to reject evolutionary biology. Early studies attributed rejection of evolution mostly to a lack of knowledge of evolution. However, recent work has helped us to expand that concept and develop a preliminary framework with which to understand the factors associated with an individual's acceptance or rejection of evolution.

Recently, a publication by over 20 scholars in evolution education sought to chart a path forward for evolution acceptance research (Dunk et al., 2019). They review the recent literature and find that evolution acceptance across populations tends to be most strongly associated with knowledge of evolution, religiosity (or intensity of religious beliefs), and an understanding of the nature of science. In addition to the review, the authors of that review also suggest directions for future research in evolution education. Here, we present results that directly addresses of those suggestions, which is to use longitudinal time frames to document possible changes in evolution acceptance over time.

For the factors described above, we used an assessment of understanding of the nature of science that included 6 subscales (Rubba and Andersen, 1978) and a measurement of evolution understanding that included 3 subscales (Hawley et al., 2011), which are described more in the methods section. In addition to the major factors, we included a factor in our model called openness to experience, which is a psychological personality trait measure associated with an individual's intellectual curiosity (John et al., 2008). While not as well established as the other variables in the model, openness to experience has been found to be significantly associated with acceptance of evolution in multiple populations (Dunk et al., 2017; Hawley et al., 2011).

Our goal in this study was to extend our knowledge of the factors associated with acceptance of evolution in three ways. First, we used multiple measures of the overarching factors associated with evolution acceptance as identified in Dunk et al (2019) to add a more detailed understanding of what aspects of those factors are responsible for the significant association seen between them and acceptance of evolution. Second, we extend our population of interest beyond biology students to a sample of the general student body. Third, our study uses a longitudinal time frame to examine change in acceptance of evolution and its associated factors, an approach which is recommended by a host of leading evolution education researchers in the previously mentioned recent review (Dunk et al., 2019).

With regards to the first goal, we expected that factors measuring understanding of evolution, understanding of the nature of science, and openness to experience would be positively related to acceptance of evolution and that religiosity would be negatively related to acceptance of evolution, in line with copious previous research. However, we did not have specific hypotheses for each of the individual factors beyond this. We hypothesized that these factors would be significant in spite of the change in population compared to the majority of evolution education research, as previous studies have found similar relationships in general college students (Rissler et al., 2014), high school students (Cofré et al., 2017b; Mead et al., 2017), and even the general public (Barone et al., 2014; Miller et al., 2006; Weisberg et al., 2018). Lastly, we expected that the addition of a longitudinal time frame would not affect these results; that is, we expected that the factors identified in previous studies (most from a single time point) would be associated with acceptance of evolution when measured across multiple time points. This has been shown in a few studies (Cofré et al., 2017b; Mead et al., 2017), most notably with a student population studied at our same institution (Carter and Wiles, 2014).

2.2 Methods

In fall 2017, surveys were administered to students in the university first year experience course near the beginning of the course via a survey link sent to all students in the course. Instructors across all sections were asked to allow time for students to complete the surveys in class and also asked to make survey participation mandatory for students at both the beginning and end of semester. Due to the hundreds of sections of the course being taught, however, instructor practices likely varied and were not tracked. Surveys were administered online via Qualtrics using a direct link. All protocols in this study were approved by the Syracuse University IRB (protocol #17-257).

We measured evolution acceptance using the Measure of Acceptance of the Theory of Evolution (MATE; Rutledge and Sadler, 2007; Rutledge and Warden, 1999). Though there are some critiques of the MATE (Smith, 2010; Wagler and Wagler, 2013), we chose to use it as it helps us maintain communication with the majority of the previous studies of evolution acceptance. Further, a recent study (Barnes et al., 2019) found that for understanding evolution, understanding of the nature of science, and religiosity, there was no difference in sign or overall significance between the factors and acceptance of evolution whether measured by the MATE or its main competitors, the I-SEA (Nadelson and Southerland, 2012) or the GAENE (Smith et al., 2016). Openness to experience, the only other factor we analyze in this study, was not included in Barnes et al.'s study. We also chose here to analyze the MATE in full; though one study found a potential two-factor structure in responses to the MATE in their population (Romine et al., 2017), the authors of that paper continue to support the use of the MATE as a one-factor instrument, as did another study which found that "interpretation and use of a single unidimensional score is equally informative and more practically efficient" (Metzger et al., 2018). Cronbach's alpha was calculated and found to be 0.94, which provides empirical support for our decisions.

To measure understanding of evolution, we included the evolutionary knowledge, evolutionary misconceptions, and genetic literacy subscales of the Evolutionary Attitudes and Literacy Survey (Hawley et al., 2011). Openness to experience was measured via the Big Five Inventory (John et al., 2008); intrinsic and extrinsic religiosity, or, respectively, how individuals use religion as a guide for personal meaning or for community, fellowship, and comfort was measured using the I/E-R scales (Gorsuch and McPherson, 1989). Understanding of the nature of science was measured by the Nature of Scientific Knowledge Scale (NSKS; Rubba and Andersen, 1978), a measure of understanding of the nature of science consisting of 6 subscales (Amoral, Creative, Developmental, Parsimonious, Testable, and Unified). Each of these measures has been validated via factor analysis in college student populations, except for the NSKS which was validated via measures of content validity, construct validity, and reliability of each subscale.

To look at change across the semester in all variables we employed a measure called normalized change (Marx and Cummings, 2007). Normalized change shows the change between two time points in a measurement on a scale from -1 (greatest decrease possible) to +1 (greatest increase possible) and controls for ceiling effects and uneven distributions with a similar measurement, normalized gain. The normalized change scores were then subjected to two analyses.

First, to provide consistency with previous studies on similar measures, individual regressions were performed on the normalized change in each variable on normalized change in the MATE. Then, the stepAIC function from the MASS R package (Venables and Ripley, 2002) was used to perform a bi-directional stepwise regression of all variables on MATE. Partial regressions were performed for each term that remained in the stepwise model and plotted to show the relationship between normalized change in acceptance of evolution and normalized change in each model term.

For the majority of this study, we focus on looking at broad changes with the hopes to describe, in the most general terms, changes that occurred in students' thinking over the semester. However, we expected that differences may exist from the inclusion of students with different educational experiences throughout the first semester of university education, specifically students who were enrolled in introductory biology throughout the semester. Thus, we checked if the final model determined by stepAIC differed when considering students' enrollment in introductory biology. We also extended the model given by stepAIC to the full dataset, which gave us a 25% increase in sample size due to students who had completed the survey measures which were in the final stepwise model, but who had not completed all survey measures which were input into stepAIC. This extended model is not independent of the stepwise model, and is presented only to give a fuller picture of the survey population.

2.3 Results

The mean, SD, median, and range of each variable from both survey administrations of the semester are included in Table 2.1. Sample sizes for this and the analyses to follow fluctuate due to participants only partially completing the survey, and are thus given individually for all tests.

Results from the individual regressions are given in table 2.2 and shown in supplemental figures 2.S1-2.S13. Significant regressions were found between an increase in acceptance of evolution and an *increase* in knowledge of evolution (R^2 = 0.092, p < 0.001), genetic literacy (R^2 = 0.081, p = 0.001), openness to experience (R^2 = 0.050, p = 0.031), an understanding of science as involving testable claims (R^2 = 0.044, p = 0.036), and an understanding of science as a unified body of knowledge (R^2 = 0.073, p = 0.007). An increase in acceptance of evolution was also significantly associated (via regression) with a *decrease* in students' intrinsic (R^2 = 0.079, p = 0.012) and extrinsic (R^2 = 0.062, p = 0.036) religiosity. Acceptance of evolution was not significantly related to evolutionary misconceptions, or an understanding of science as amoral, creative, developmental, or parsimonious.

All significant terms were put into a stepwise regression model along with a term that identified if each individual was enrolled in introductory biology for the semester. This model is shown in Table 2.3. As can be seen, not all variables that had a significant regression with acceptance of evolution were included in the model. Notably, an understanding of science as involving testable claims and extrinsic religiosity were not included in the model, and openness to experience was included but not a significant factor.

The factors that showed a significant relationship with acceptance of evolution were, in order of beta coefficient, an understanding of science as a unified body of knowledge (B = 0.433 ± 0.114, $p < 0.001$), intrinsic religiosity (B = –0.305 ± 0.102, p = 0.004), knowledge of evolution (B = 0.275 ± 0.115, p = 0.020), and genetic literacy (B = –0.249 ± 0.114, p = 0.034). In comparison, the insignificant term openness to experience had a beta of 0.231 ± 0.148 and a p-value of 0.127. Overall, the model had an adjusted R^2 value of 0.4126, meaning over 40% of the variation in acceptance of evolution was accounted for by the terms in the model. Figure 2.1 shows the partial regression from each significant model term, and the partial regression for openness to experience is shown in figure 2.S13.

We assessed model quality both by checking the normality of residuals and calculated variance inflation factors (VIFs) to check for multicollinearity between terms (Fox and Monette, 1992). All VIFs were below 1.5, which is well beneath any suggested cutoff (Zuur et al., 2010), which suggests no problematic multicollinearity. Residual plots (Q-Q plot and residuals vs fitted values) were viewed and seemed to be acceptable, but to confirm, a Shapiro-Wilk normality test was performed on the residuals; they were found to not deviate significantly from normality (W = 0.97, p = 0.1256). Additionally, to be sure that each variable included in the final model did not vary based on students' enrollment in introductory biology, the final model was rerun five times with an added interaction term between each predictor variable and enrollment in intro bio. The interaction term was not significant in any of these models.

This stepwise model was slightly limited by the number of students who had completed all survey instruments for all variables considered in the stepwise regression, not just those which were retained in the final model. Thus, we reran the analysis with the general dataset. This gave a 25.9% increase in sample size (N= 68, compared to 54 for the stepwise model). This "extended" model is also given in table 2.3. Model terms were similar enough not to be repeated here, except that genetic literacy was not significant in this extended model (B = –0.175 ± 0.112, p = 0.124). Compared to the stepwise model, this extended model explained a similar amount of the total variation in acceptance of evolution, with a model adjusted R^2 value of 0.3896.

2.4 Discussion

On average, the students surveyed were found to have an average of around 83 at the beginning of the semester, and 84.6 at the end of the semester, with overlapping standard errors (Table 2.1). Both of these scores are in the "high acceptance" range as defined by Rutledge and Sadler (2007). This is not unique among studies, including those at the same institution (Carter and Wiles, 2014; Dorner and Scott, 2016; Metzger et al., 2018), though other studies that use the MATE generally find a lower acceptance level (Cavallo and McCall, 2008; Grossman and Fleet, 2017; Rissler et al., 2014; Rutledge and Sadler, 2007; Wiles and Alters, 2011).

The subscales of the NSKS all contain the same number of items scored similarly, so analyzing the differences between scores shows areas where students have relatively stronger understanding of the nature of science compared to others. First-years students in this study tended to have stronger understandings of the testable, unified, and developmental subscales of the NSKS, compared to the amoral, creative, and parsimonious subscales (Table 2.1). These patterns, and to some extent the overall means, are similar to that seen in the development of the measure (Rubba and Andersen, 1978) as well as more recent implementations of the NSKS (Folmer et al., 2009; Owens and Foos, 2007). All subscales, however, had a mean under 31, indicating only around 72% of the possible full score on these subscales. Thus, even for those areas where students showed a stronger understanding, there is room for improvement. Of all the subscales, it seems students were least likely to understand the parsimonious nature of science.

Much of this might be attributed to students' personal experiences with science, which can often be an area of study that students find complicated. However, as parsimony is an integral part of scientific understanding and process (such as, for example, its crucial role in evolutionary theory Albert, 2005), it is especially important that students understand how scientific claims are as simple as possible, even when they are complicated.

We found that normalized change in certain measures of understanding the nature of science, understanding of evolution, and openness to experience were significantly and positively related to normalized change in acceptance of evolution, in line with our expectation (Table 2.2). Specifically, we found that an increase in genetic literacy or an increase in evolutionary knowledge were associated with an increase in acceptance of evolution, while changes in evolutionary misconceptions did not have a significant relationship with evolution acceptance. This is in line with the original paper detailing these scales, which found that the misconceptions measure tended to be less strongly negatively correlated with measures of creationist reasoning and beliefs when compared to the other two scales (Hawley et al., 2011). Further, the misconceptions measure may be too specific in that it only measures specific (though well-documented) misconceptions, while the others measure more general knowledge. It is perhaps not surprising that a tool developed to measure evolutionary misconceptions in Kansas may not be as effective in the Northeast U.S., given the very different political and religious landscape between the two.

The NSKS normalized change measures that showed a significant relationship with normalized change in acceptance of evolution were understanding science as requiring testable claims and as a unified body of knowledge, while the amoral, creative, developmental, and parsimonious subscales were unrelated to acceptance of evolution (Table 2.2). These subscales have not specifically been used in relation to evolution acceptance (besides other work of ours that is in the prepublication stage and shows a similar trend; Dunk and Wiles, 2018), so we do not have specific comparisons to make to these results and others. We were not surprised that the testable and unified subscales showed a significant association with acceptance of evolution. Evolutionary biology is a science which relies on and has implications for many diverse fields of study, and like all science, relies on making and upholding testable claims as the foundation for evidence. However, we were a bit surprised that there was no significant relationship between some of the other subscales. Evolution relies heavily on parsimony and continual refinement and development of its claims, and is often taught specifically in way that highlights the development of evolutionary thought from a Lamarckian to a Darwinian to a Synthetic framework. Further, especially given the tension between religious beliefs and evolution acceptance that many individuals feel (Barnes and Brownell, 2017), we were surprised there was not more of a relationship between accepting evolution and understanding the inability of science to make moral claims (which is much more the purview of religion). Though the survey tool (Johnson and Peeples, 1987) most often used in connection with evolution acceptance (Barnes et al., 2019; Dunk et al., 2017; Glaze et al., 2015; Rutledge and Warden, 2000) does not have any single identification with the factors in the NSKS, it includes many questions about the limits of scientific knowledge as well, so we are further surprised that our study shows no association between accepting evolution and understanding the limitation regarding science's inability to make moral claims.

When looking at the single regression, both measurements of religiosity we looked at were significantly associated with evolution acceptance. Specifically, a decrease in intrinsic religiosity (the degree to which religion influences personal understanding and decision making) was associated with an increase in acceptance of evolution, and a decrease in extrinsic religiosity (the importance of religious worship and religious communities for an individual) was associated with an increase in acceptance of evolution as well (Table 2.2). This generally agrees with previous studies; while they did not explore the different facets of religiosity by name or direct intent, previous research has found aspects of both intrinsic (Glaze et al., 2015; Lombrozo et al., 2008; Nadelson and Sinatra, 2009; Trani, 2004) and extrinsic (Carter and Wiles, 2014; Manwaring et al., 2015; Rissler et al., 2014) religiosity to be significantly related to acceptance of evolution.

The final variable we found to be related to change in acceptance of evolution was change in openness to experience (Table 2.2). That is, students who increased in their openness to experience over the semester also tended to increase in their acceptance of evolution. This relationship, when examined in a single data collection rather than longitudinally, has been found in other populations (Dunk et al., 2017; Hawley et al., 2011), but not all (James et al., 2015). In addition, other psychological variables related to intellectual curiosity have been found to be related to evolution acceptance as well (Sinatra et al., 2003). Due to these other studies we were not surprised that this relationship was significant, though openness is generally considered to be a stable trait (Hawley and Sinatra, 2019), so we were somewhat surprised to see any measurable shift in it at all.

When we combined the above significant factors into a stepwise regression model, we found that individual model terms that represent each major factor in evolution acceptance as defined by Dunk and colleagues (2019) were significant our model (Table 2.3). Specifically, we found that two terms representing understanding of evolution were significant (the evolutionary knowledge and genetic literacy subscales of the EALS), while understanding the nature of science and religiosity were represented by a single model term. The removal of the NSKS testable term and extrinsic religiosity is not surprising and is likely due to a large amount of shared variance between them and the similar model components retained in the stepwise model, though based on previous work we would have generally expected that an understanding of the testable nature of science would have been more important than an understanding of the unified nature of science. In addition, openness to experience was included in the model, but it was insignificant. Extending our model to include more individuals in the sample provided further support for the relationship between change in acceptance of evolution and changes in the unified nature of science, evolutionary knowledge, and intrinsic religiosity.

By far the most surprising finding of the stepwise regression was a change in sign for genetic literacy when compared to the single regressions. By itself, we found that increasing genetic literacy was associated with an increase in evolution acceptance, which is expected and in line with other research on evolution acceptance (Hawley et al., 2011). However, when included in the stepwise regression model, the relationship changes sign– when controlling for evolutionary knowledge, intrinsic religiosity, openness to experience, and an understanding of science as a unified body of knowledge, increasing genetic literacy is significantly associated with a *decrease* in acceptance of evolution. The sign of this relationship holds in the extended model, though it is no longer a significant model term. This gives some indication that it may be simply a statistical anomaly due to some indeterminable aspect of the sample reduction between the single regressions and the stepwise model. However, the finding warrants follow-up, as we are unable to come up with any reasonable suggestions as to why increased understanding of genetics would be associated with decreased acceptance of evolution, even when accounting for all other variables in the model.

2.5 Conclusions

Though this study uses a longitudinal time frame and a more general student population than the majority of studies in evolution acceptance, we found that the three main aspects associated with acceptance of evolution in previous studies were also significantly and independently associated with acceptance of evolution in our study. Looking across the first semester of college in general arts and sciences students, increased knowledge of evolution and/or increased understanding of the nature of science was associated with increased acceptance of evolution, while decreased religiosity was associated with an increased acceptance of evolution. We found that this was independent of other changes and not specifically associated with enrollment in introductory biology. We further found some evidence that when accounting for other model terms, an increase in genetic literacy may be associated with a decrease in evolution acceptance in the students tested. So far, this finding is unique to our study, but further investigation into the link between understanding genetics and accepting evolution is necessary. This study shows that aspects of individuals known to be related to acceptance of evolution in biology students are similar amongst a more general student population. Further, the link between increasing knowledge of evolution or increasing understanding of the unified nature of science and increased acceptance of evolution suggests that attempts made to increase learning in either of those subjects may have payoff in increasing acceptance of evolution.

2.6 Acknowledgements

The authors would like to thank Gerald Greenburg, the First Year Experience program at Syracuse University, and all of the instructors of First Year Forum for their assistance in providing access to the student population used in this study. This work was partially funded by a Rosemary Grant Award from the Society for the Study of Evolution awarded in 2017 to RDPD.

2.7 Figures and Tables

Table 2.1. Summary statistics for acceptance of evolution and related variables in this study.

Beginning of semester						End of semester				
Mean ± SE	SD	Median	Range	N	Variable	Mean ± SE	SD	Median	Range	N
82.97 ± 0.54	13.25	85	32–100	605	Acceptance of Evolution	84.57 ± 1.07	14.49	89	50–100	183
27.8 ± 0.19	4.49	28	15–35	542	Evolutionary Knowledge*	28.78 ± 0.29	4.18	29	17–35	201
12.55 ± 0.17	3.96	13	0–21	543	Evolutionary Misconceptions	12.80 ± 0.34	4.76	13	3–21	201
20.04 ± 0.18	4.10	19	0–28	543	Genetic Literacy	20.05 ± 0.31	4.33	19	11–28	200
169.26 ± 1.04	18.29	170	132–216	309	Nature of Science (NOS) Total	171.24 ± 1.72	20.77	171	135–220	145
27.28 ± 0.27	4.81	26	15–40	319	NOS Amoral	27.69 ± 0.40	4.92	27	18–40	148
25.65 ± 0.29	5.28	25	8–38	336	NOS Creative	25.67 ± 0.44	5.31	26	8–38	147
29.84 ± 0.24	4.49	30	17–40	337	NOS Developmental	30.01 ± 0.37	4.55	30	19–38	149
23.63 ± 0.18	3.28	24	15–36	339	NOS Parsimonious*	24.90 ± 0.32	3.85	24	14–38	147
30.90 ± 0.31	5.75	31	14–40	339	NOS Testable	31.46 ± 0.52	6.29	33	17–40	149
30.94 ± 0.28	5.24	31	16–40	340	NOS Unified	31.52 ± 0.45	5.51	32	19–40	147
36.84 ± 0.29	5.66	37	16–49	375	Openness to Experience	36.86 ± 0.45	5.84	37	18–48	165
19.15 ± 0.40	6.96	19	8–39	306	Intrinsic Religiosity	18.83 ± 0.61	7.52	18	8–39	150
14.51 ± 0.32	5.56	15	6–30	306	Extrinsic Religiosity	14.28 ± 0.48	5.90	15	6–27	150

Table 2.2. Results of correlations between normalized change of acceptance of evolution (MATE score) and normalized change of 12 different independent variables.

Variable regressed on Acceptance of Evolution	**N**	**B ± SE**	R^2	p
Nature of Science Understanding Total (NSKS)	71	0.76 ± 0.25	0.121	0.003
NSKS Amoral	101	0.03 ± 0.11	0.001	0.776
NSKS Creative	101	0.05 ± 0.11	0.002	0.629
NSKS Developmental	101	0.12 ± 0.11	0.014	0.246
NSKS Parsimonious	100	-0.05 ± 0.12	0.002	0.689
NSKS Testable	100	0.19 ± 0.09	0.044	0.036
NSKS Unified	100	0.26 ± 0.09	0.073	0.007
Genetic Literacy	125	0.33 ± 0.10	0.081	0.001
Evolutionary Knowledge	123	0.33 ± 0.09	0.092	<0.001
Evolutionary Misconceptions	125	-0.13 ± 0.08	0.020	0.112
Openness to Experience	93	0.37 ± 0.17	0.050	0.031
Intrinsic Religiosity	79	-0.27 ± 0.11	0.079	0.012
Extrinsic Religiosity	71	-0.26 ± 0.12	0.062	0.036

Table 2.3. Results of stepwise linear regression on normalized change of acceptance of evolution (MATE score) for both the stepwise model and extended model (see text for details on models). Variables that are significant in one model but not the other are indicated with a dagger (†).

	Stepwise model (N=54)			**Extended model (N=68)**		
Variable	**B ± SE**	**t**	***p***	**B ± SE**	**t**	***p***
Intercept†	0.09 ± 0.04	2.24	0.030	0.06 ± 0.04	1.47	0.148
NSKS Unified	0.43 ± 0.11	3.79	<0.001	0.41 ± 0.10	2.87	0.006
Genetic Literacy†	-0.25 ± 0.11	-2.18	0.034	-0.17 ± 0.11	-1.56	0.124
Evolutionary Knowledge	0.27 ± 0.11	2.40	0.020	0.31 ± 0.11	2.87	0.006
Openness to Experience	0.23 ± 0.15	1.55	0.127	0.29 ± 0.16	1.80	0.077
Intrinsic Religiosity	-0.30 ± 0.10	-2.98	0.004	-0.36 ± 0.10	-3.61	<0.001
Adjusted R^2	*0.4126*			*0.3896*		

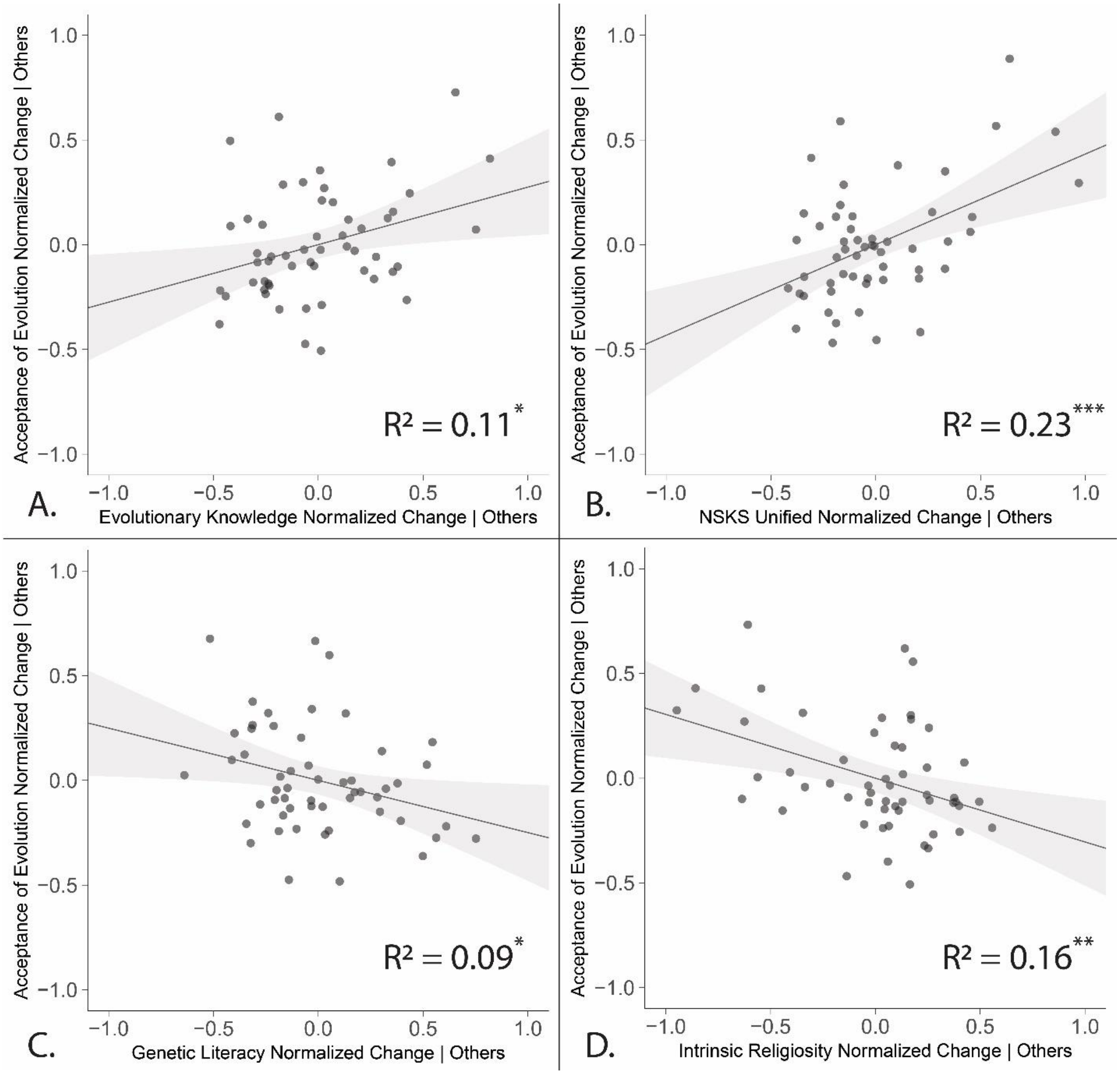

Figure 2.1. Partial regressions for each significant term in the stepwise model. Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

2.8 Supplement

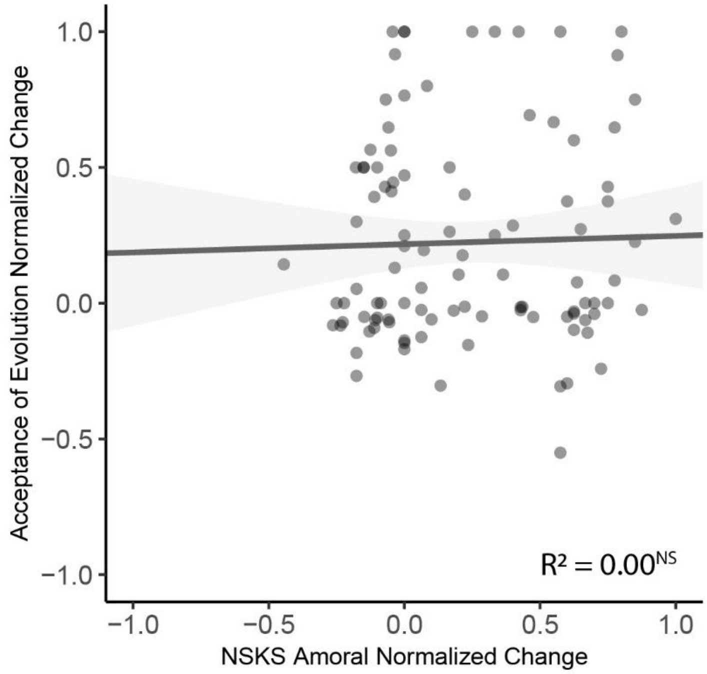

Figure 2.S1. Regression of normalized change in the NSKS Amoral measure on normalized change in acceptance of evolution as measured by the MATE.
Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, NS = Not Significant.

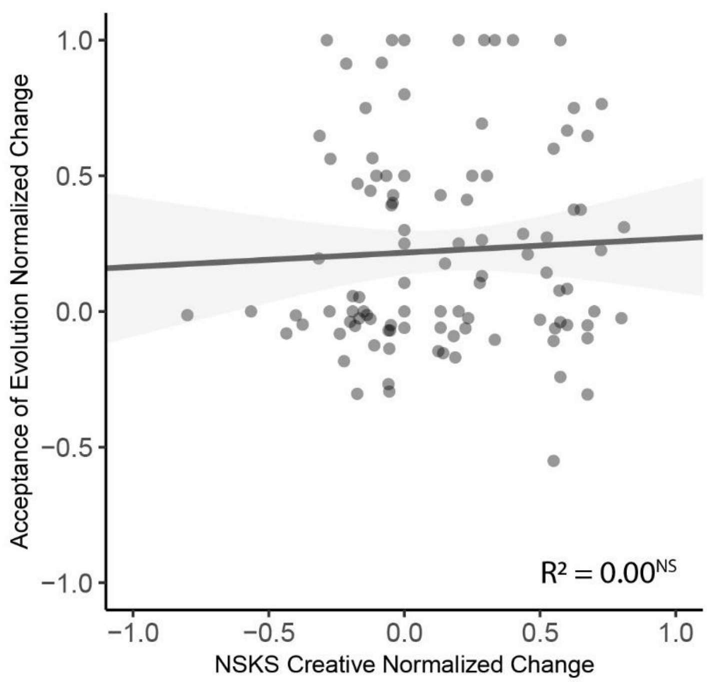

Figure 2.S2. Regression of normalized change in the NSKS Creative measure on normalized change in acceptance of evolution as measured by the MATE.
Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, NS = Not Significant.

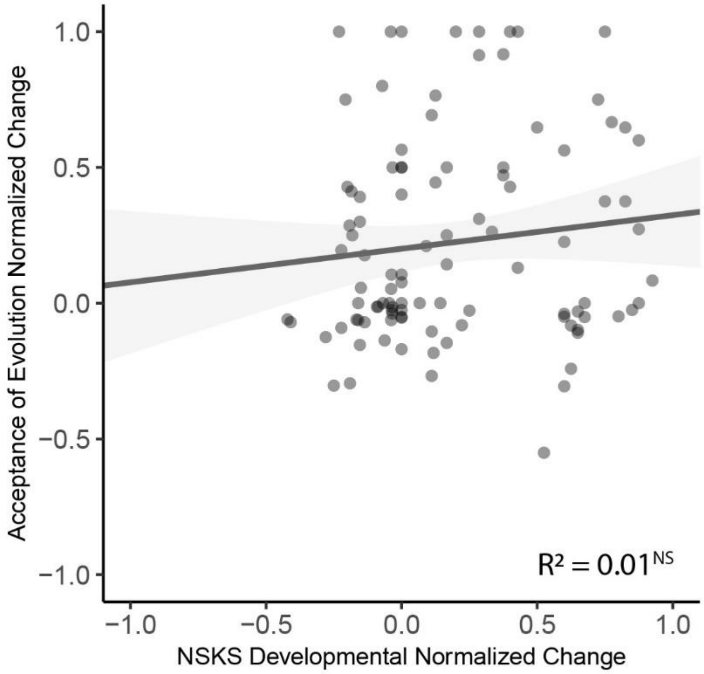

Figure 2.S3. Regression of normalized change in the NSKS Developmental measure on normalized change in acceptance of evolution as measured by the MATE.
Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

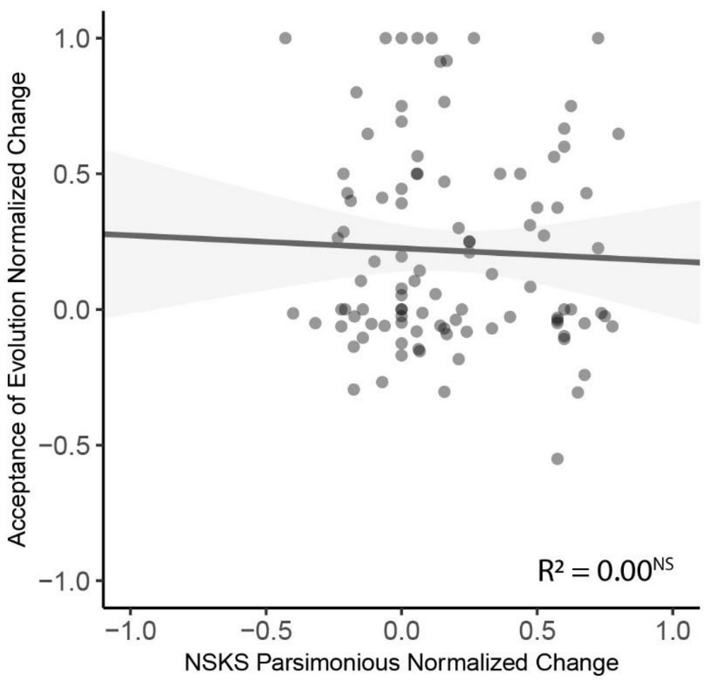

Figure 2.S4. Regression of normalized change in the NSKS Parsimonious measure on normalized change in acceptance of evolution as measured by the MATE.
Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

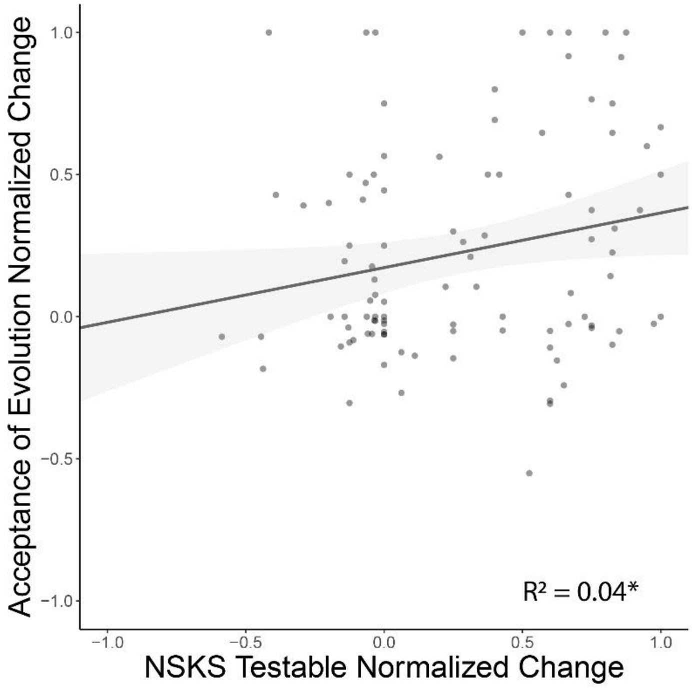

Figure 2.S5. Regression of normalized change in the NSKS Testable measure on normalized change in acceptance of evolution as measured by the MATE.
Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

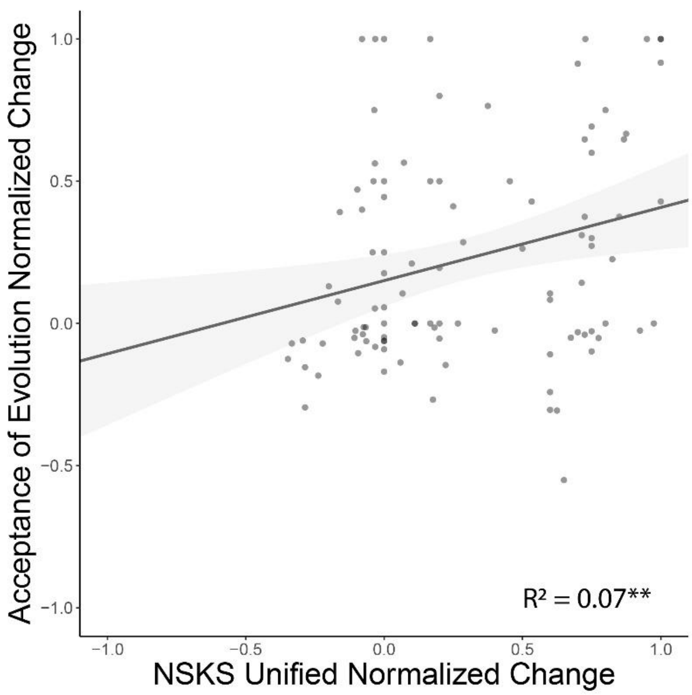

Figure 2.S6. Regression of normalized change in the NSKS Unified measure on normalized change in acceptance of evolution as measured by the MATE.
Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

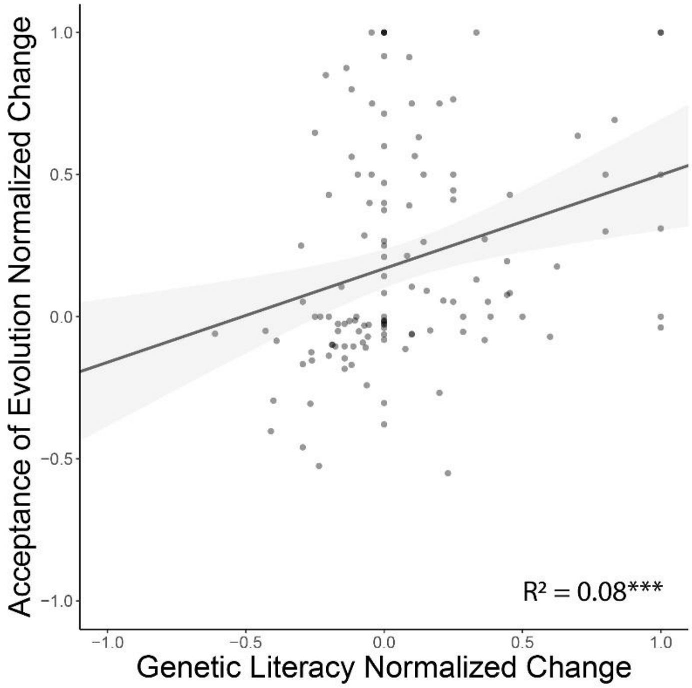

Figure 2.S7. Regression of normalized change in genetic literacy on normalized change in acceptance of evolution as measured by the MATE.

Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

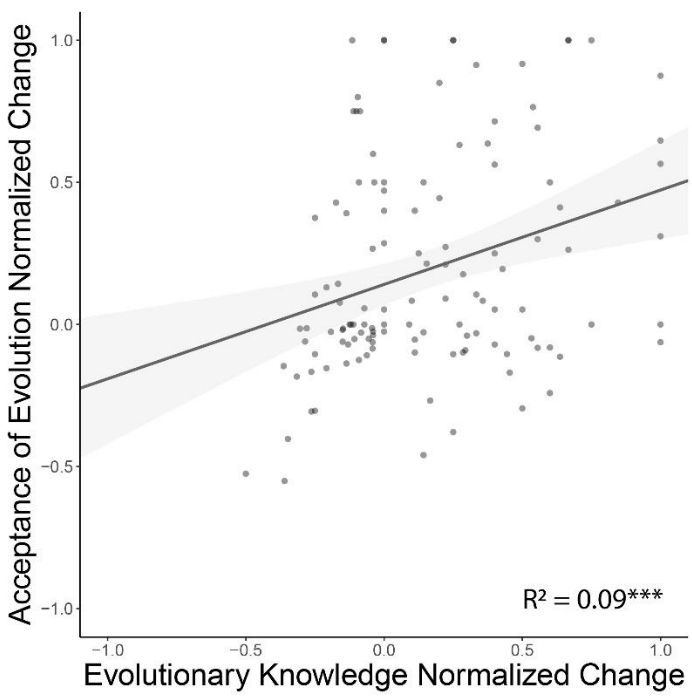

Figure 2.S8. Regression of normalized change in evolutionary knowledge on normalized change in acceptance of evolution as measured by the MATE.

Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

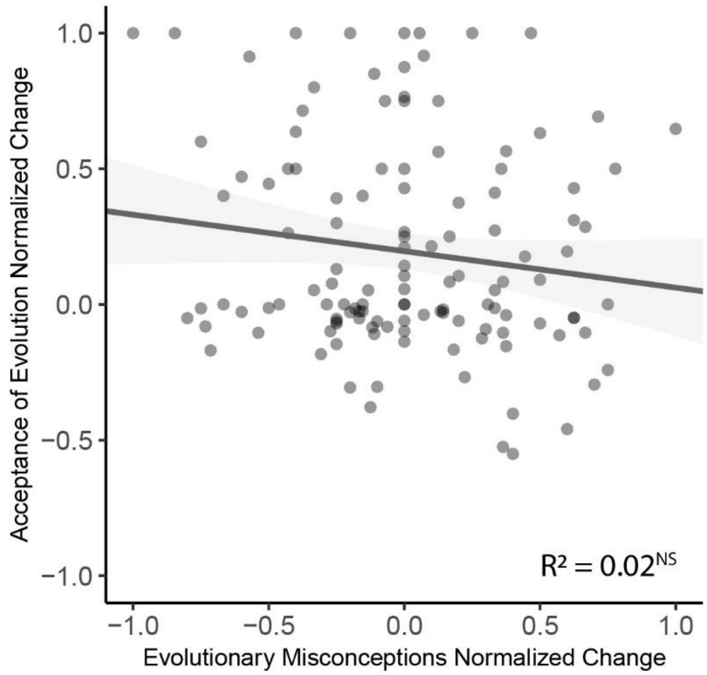

Figure 2.S9. Regression of normalized change in evolutionary misconceptions on normalized change in acceptance of evolution as measured by the MATE.

Significance: * = p < 0.05, ** = p < 0.01, *** = p < 0.001, NS = Not Significant.

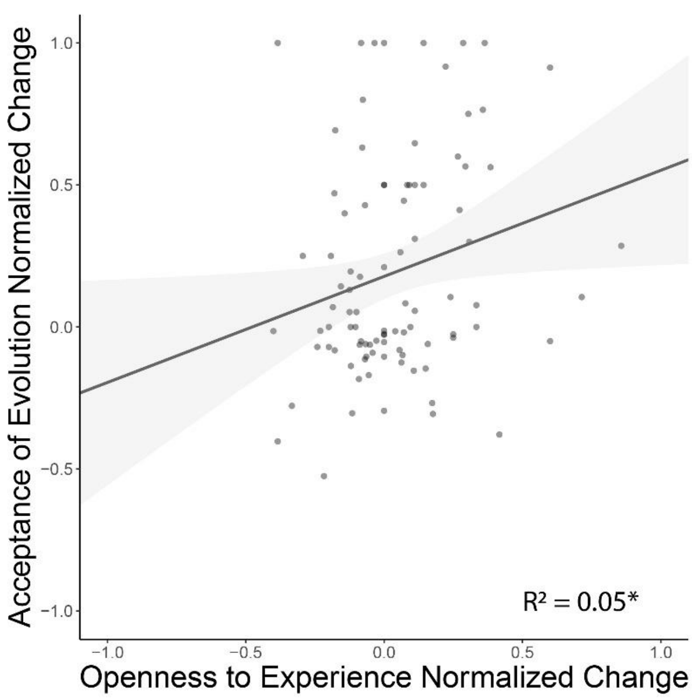

Figure 2.S10. Regression of normalized change in openness to experience on normalized change in acceptance of evolution as measured by the MATE.

Significance: * = p < 0.05, ** = p < 0.01, *** = p < 0.001, NS = Not Significant.

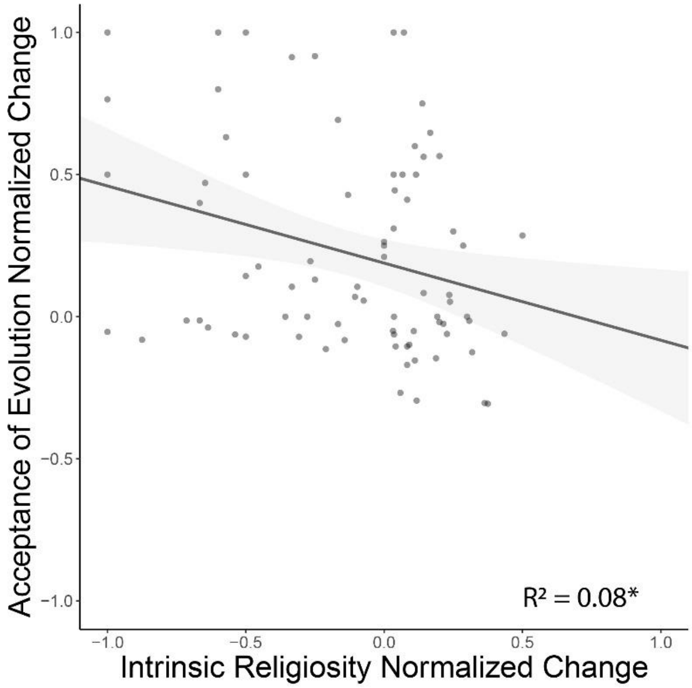

Figure 2.S11. Regression of normalized change in intrinsic religiosity on normalized change in acceptance of evolution as measured by the MATE.
Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

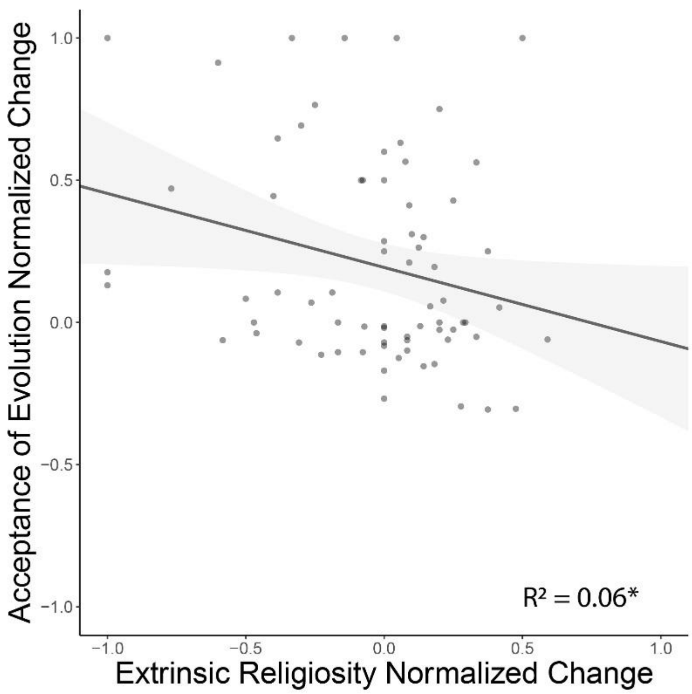

Figure 2.S12. Regression of normalized change in intrinsic religiosity on normalized change in acceptance of evolution as measured by the MATE.
Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

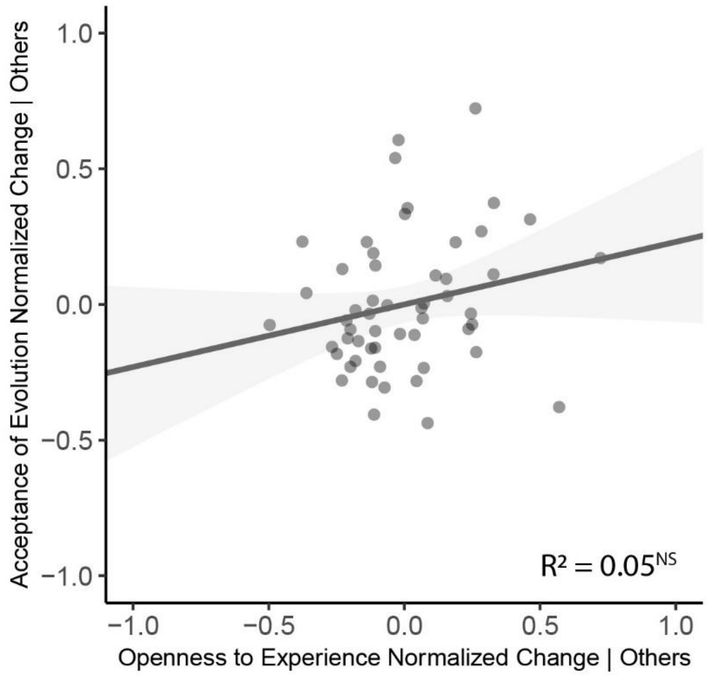

Figure 2.S13. Partial regression of normalized change in openness to experience on normalized change in acceptance of evolution when accounting for all other variables in the stepwise model. Significance: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, ^{NS} = Not Significant.

Chapter 3. Students' perspectives on their acceptance of evolution.

3.1 Introduction

Rejection of evolutionary biology is a common attitude in the United States, with over 40% of American adults agreeing that humans have been created within the last 10,000 years by God (Gallup, 2014). This level of rejection of evolution is not necessarily unique, but evolution acceptance in the U.S. is lower than many other nations in the world, including most of Europe and Japan (Miller et al., 2006). This rejection is somewhat unique, however, among scientific topics (climate change notwithstanding). Evolution is central to an understanding of all biological phenomena (Dobzhansky, 1973), and thus a rejection of evolution leads to misunderstandings of a process central to understandings of agriculture, medicine, and other topics that rely heavily on biology.

Previous work (including that in chapters 1 & 2) has shown some of the factors known to be closely associated with evolution acceptance, and they are discussed in more detail in the conceptual framework below. However, the majority of that work in evolution acceptance is quantitative. While quantitative work is beneficial in allowing us to condense a large amount of variation in a population and determine the reasons an average individual has the level of evolution acceptance they may have, in doing so it creates its own limitations. Quantitative work tends to ignore or reduce variation. However, there is value in this variation and in understanding the nuance of a problem like evolution rejection. Using a diversity of approaches can help us to gain greater understanding of the problem than one methodological approach alone can.

This study builds on this quantitative work by adding a qualitative investigation into the problem of evolution acceptance. While this is not the first work to explore evolution acceptance qualitatively (Borgerding et al., 2017; Donnelly et al., 2009; Wiles, 2014), it is among the first to do so after the review articles that form the conceptual framework used in this study were published, allowing additional potential insights. Further, the use of a subsample of students from chapter 2 allows this work to serve as a mixed-methods explanatory follow-up to those findings.

3.1.1 Conceptual Framework

This study is situated within a developing framework of evolution acceptance, framed by two recent reviews of the evolution acceptance literature. Pobiner (2016) recently reviewed the history and current focus of research on the acceptance of evolution, and (among other things) provides a thorough summary of factors that have been shown to be related to evolution acceptance. A more recent paper (Dunk et al., 2019), jointly authored by 20 active researchers on evolution acceptance, provides context to these factors and helps to chart a direction for further research towards developing a theoretical framework for evolution acceptance.

The most prominent factors associated with evolution acceptance are (1) knowledge of evolution, (2) knowledge of the nature of science (NOS), and (3) religious affiliation and intensity of religious belief. The first two factors show a positive relationship with evolution acceptance, while increased religiosity often leads to decreased acceptance of evolution, especially among those of Abrahamic faith. While further research into finding additional factors associated with evolution acceptance is not unwarranted, Dunk and his colleagues (2019) argue that researchers of evolution acceptance should instead focus on work geared towards determining the generalizability of known results and investigating evolution acceptance across a longitudinal framework. Here, we take up both of those challenges by interviewing students about their changing views and attitudes of evolution acceptance.

3.1.2 Expectations

We explored how a general body of students explained their acceptance of evolution using semi-structured interviews conducted on students in their second and third years of university education. We expected, based on previous studies at our university, to find that students were generally accepting of evolution. Due to the findings from chapter 2, we expected that students would relate their acceptance to their knowledge of evolution, their religious attitudes and practices, and their understanding of the nature of science. Of these, we expected that the first two would make up the majority of the responses due to the way they have direct ties to student's lived experiences, and expected that more direct questioning would be needed to elicit student responses regarding the relationship between their understanding of science and acceptance of evolution.

3.1.3 Positionality Statement

Qualitative research is inherently personal for both the subjects and the researcher. Though this is true of quantitative research as well, the reliance on personal narrative rather than figures and tables makes qualitative research especially amenable to alternate interpretations based on an author's experience. Positionality statements are a reflexive statement about the researcher's role in the knowledge process, and attempt to provide transparency in the research process by a frank discussion of the potential for bias in results due to the personal limitations of the researcher's lived experience. Growing out of feminist qualitative research, positionality statements also seek to expose the power relationship between researcher and subject (Rose, 1997).

I, RDPD, the interviewer and coder for this study, am a biologist and firmly accept evolutionary biology as the best explanation for the diversity of life on earth. I would not consider myself a religious person and was not raised with a lot of religious influence in my life;

I was raised with some Christian religious influence, and both of my parents maintain religious influences in their lives, though neither is particularly devout.

As an interviewer my goal was to remain nonjudgmental and supportive of students' explanations of their personal attitudes, feelings, and concerns regarding evolutionary biology as well as the factors they felt were associated with that. However, participants were likely aware of my personal attitudes in some respect. Our recruitment email mentions that "we are specifically in students' understanding and acceptance of evolutionary biology"; though it does not directly state whether we support evolution or not, combined with the surveys these students took previously, they were likely aware that I supported evolutionary biology. This could lead to statements which lean more towards acceptance than would be given if the students were speaking to someone with different biases. Further, though I did my best to remain true to the spirit of each individual's responses, there is definitely the possibility for bias in interpretation of individual's words given my own positionality. Thus, I have tried to include much of the original text of the interviews in the results, to show the raw data and not allow my interpretation of the students' views dominate the narrative.

3.2 Methods

Students at a private, large, research-intensive (Carnegie R1) university in the northeastern US were surveyed at the beginning and end of the fall 2017 semester. Students were enrolled in a first year experience course run across many sections throughout the university. Participation in research was voluntary, but surveys were offered to instructors as possible required course components. All sections of the course received emails asking for their participation, but requirements placed on students to complete the surveys differed by section.

For all semesters, surveys were administered online via Qualtrics or Blackboard. All protocols in this study were approved by the Syracuse University IRB (protocol #17-257).

In spring and fall of 2019 students who agreed to be contacted for follow-up were sent an email asking them to sit down for 20-40 minute long interviews. Students were offered compensation for participation of a $5 gift card to Amazon.com and a drawing into a $500 gift card prize to the retailer of the winning recipient's choice. Interviews (n=13) were audio recorded using a standard stand-alone audio recorder. All interviews were initially transcribed via using the Trint program, and these initial transcripts were read over while listening to the recordings and edited for accuracy. These final, verified transcripts were read and analyzed by me using open coding. Codes were combined into themes and analyzed for commonality and differences between interview subjects.

Subjects are referred to throughout by their chosen pseudonym. Subjects came from a variety of majors. They were not specifically asked, but some offered the information; participants mentioned political science, sociology, international relations, philosophy, communication science and disorders, forensic science, and of course, biology. This offers evidence that this wave offers a true follow-up to chapter 2, and represents a diverse student population, not only those who are from a major where evolutionary biology is heavily emphasized in the curriculum.

These interviews were semi-structured and sought to elicit student reasoning and attitudes around acceptance of evolution. Each interview pursued a somewhat different focus, as each respondent was allowed to discuss what things they felt were important in the development and change of their attitudes surrounding acceptance of evolution, and as interviewer I saw my primary goal as being reflexive to the natural direction of the subjects' thoughts. All students in this chapter were among those who were surveyed in chapter 2. This chapter is to add nuance to that chapter by using qualitative methods to explore the themes found important in the students' acceptance of evolution in that chapter. While this chapter focuses only on the qualitative results, chapter 2 and 3 together form an explanatory mixed methods approach (Creswell and Plano Clark, 2011). In explanatory mixed methods studies, qualitative data is collected to follow up on the main themes confirmed by qualitative analyses, while qualitative analysis are given priority weighting in the description of the phenomenon being explored.

3.3 Results

Level of acceptance of evolution

The students in this study were accepting of evolution for the most part, with no students expressing opinions that reflected rejection of evolution, though some did not outright exclaim their acceptance of evolution. When students did explicitly describe their level of acceptance, it was often in terms indicating a very high acceptance. Emma described themself as a "big believer" in evolution, that it "always just made sense to me", and they "never really believed in anything otherwise". Jenny echoes this: "I think there's lots of proof. I think it's very plausible, if not already a fact. Yeah, I accept evolution, 100%." For Island Girl, this acceptance was so strong that they had difficulty even conceiving of people who would not believe in evolution:

> I feel like a lot of us have been exposed to it for so long that it just seems like crazy that people won't accept it to us. So I think that a lot of us were like on that side of the spectrum, of being very accepting… But I think it was something crazy like 75 percent or 80 percent of - or even maybe more- of the population just doesn't believe in evolution at all. I think like I was SHOCKED because my high school like I said, we had exposure throughout the years we talked about it. (Island Girl)

Here, and for the rest of this paper, we are equating the terms "belief" and "acceptance". Evolution education researchers tend to prefer the term "acceptance" over "belief", indicating a reliance on evidence to accept scientific claims (Southerland and Sinatra, 2003). However, it is unlikely that students have similar differentiation, and it has been recommended to treat them as the same in self-reports from research participants (Nehm and Schonfeld, 2007).

Acceptance in school

From all interviews, the most often discussed source of evolution acceptance was high school experiences. Ten of the interview subjects specifically mention their high school experiences in relation to their acceptance of evolution, and some participants noted learning about evolution at younger ages, in middle and even elementary school. These high school experiences ranged from biology taken in 9th grade through AP Bio. Participants attended high school in a range of different environments: standard public schools, schools “specialized in science and math” (Sasha), an “extremely, extremely progressive high school” (Emma), and even Catholic high schools:

> Yeah. So my Catholic school was an all girls school. I was in New York City, Upper East Side. We only took one bio, but I took a science every year after that. I think bio was my favorite one… So they did like encourage sciences and stuff like that. There was– I never felt repressed when it came to like bio, the things you teach you in biology. Thank God. …they had a very positive outlook on science. And they did their best to get us all into science classes all of the time. …we were a Catholic school, but they taught us evolution anyways, which was nice, right? New York City, Oooo, y'know? (Jenny)

Most students only discussed positive experiences related to evolution in high school, but some mentioned anti-evolution experiences. Emma, despite their very progressive high school, had their general biology teacher discuss opposition to evolution:

> But I really think we only spent one day and it was probably 20 minutes in a fifty five minute class saying, “some people don't believe in evolution. Most of it is religious. Like for religious reasons. That's really it. You can take that how you want. But I'm not. I'm gonna teach you evolution. It's not gonna be... I'm not going to really elaborate on the other side.” (Emma)

Emma’s AP Biology teacher was more direct on articulating the science (“my [AP] biology teacher was like, ‘There is evolution and that's it. There's really no other way.’”), and this had a big impact on Emma’s acceptance:

> I think that because I had such blind faith in my teachers when I was younger, that became my logic. If that makes sense, like them teaching me evolution and you know, the typical diagram of ape to human across that spectrum of time. That just made sense to me. And obviously I haven't taken biology in a very long time at this point. But all of the evidence that was presented to me for evolution, all just kind of clicked like I couldn't I couldn't see any other way of like how things progressed for all species, I guess. And I don't know if that's, you know, because that's all I've ever been taught or what, but that's just I never thought to question it, I guess.

It is clear, however, that discussing anti-evolution views left their mark on these interview participants. David spoke of a teacher in their school who expressed creationist views:

> David: Y'know. It's funny that you bring up that experience from high school because. So for me personally, my high school teacher, who taught biology, she didn't deny evolution. But there was actually another teacher in the high school who didn't believe in evolution and she was teaching biology. And to me, I just thought that was really surprising. How do you get a job teaching biology if you don't believe in evolution?... But yeah, she was like, oh, well, there are other theories, like implying intelligent design.”

David was the only participant who mentioned a teacher who was directly anti-science, however. Like Emma, other participants mentioned their teachers defending evolution:

> And one of the kids felt like facetiously, very like jokingly said, I don't believe in evolution. You can't teach me this. And then the teacher was like, no, it's real and I'm going to teach it to you. You don't have to believe it, but it's it's happening. (Individual One)

> Yeah. I remember when I was a junior in high school, I took AP bio and when I was in my AP bio class, I loved my teacher. And he– it was in 2016, which was a very controversial time because it was during the election and there was a lot of talk about the– about like people rejecting science, like specifically when it came to global warming and things of this nature. So I remember my teacher speaking about evolution in a very defensive manner, being like "It IS, like, this is actually what happened, like people don't believe this.” (Emily)

This defense of evolution may correspond to high school being the first time participants were aware of anti-evolution views, as Coffee specifically mentioned. Others, however, noted university as the first time they encountered anti-evolution beliefs. Island Girl, quoted above, expressed their shock at learning how many people do not accept evolution (though the number quoted was a bit inaccurate). Emma further described this realization from their perspective:

> It wasn't until I came to college and I realized that people... I think just growing up, being in college, you have more academic related conversations than I did in high school with my peers. And so it wasn't until I came here that I started having conversations with people who weren't taught the same way as me. So I have friends who weren't taught evolution in elementary school like I was. And so they have a different view on it because it wasn't instilled in them at such a young age... like I said, I've never been taught anything otherwise. And all of my friends growing up have never been taught anything otherwise. So it was never really a conversation that needed to be had because we would just all agree and move on. But here it's a little bit different. I would say all of my friends here believe in evolution, but they had to come to that conclusion on their own, not from their teachers, because they had teachers who were saying evolution isn't real. In middle school or whatever it was. (Emma)

Here we see that though Emma seems to have friends who are accepting of evolution, her interaction with them helped her become more informed and understanding of those who reject evolutionary biology.

Informal exposure to evolution

One factor that has been shown to be associated with higher acceptance of evolution is informal exposure to evolution outside of schools (Hawley et al., 2011). Some students expressed experiences outside of school that related to their general appreciation for science, such as science fairs or books. However, the only experience students noted related to evolution was their trips to natural science museums. Multiple students specifically recalled the American Museum of Natural History:

> I did go to– what is that museum in the ci– the Museum of Natural History. I would go there and I saw like the evolution exhibit there. And, you know, I always just thought it was like, really fascinating. (David)

> I've been there like a billion times, like I have it memorized. I love it, though. It's my favorite museum… There's this giant whale in the like aquatics thing. It's this huge whale. And like I remember they wanted us to stand under it. It was massive. And I was like, this thing is real? Like, it's just swimming out there?... It was really cool. But I didn't understand that it was science. I just thought it was animals. (Jenny)

Still, most mentions of science museums were related more to general science interest than evolution knowledge specifically.

Family impacts on evolution acceptance

Another theme that participants discussed was how their family impacted their views on evolution. David experienced this most directly, as their grandfather was a biologist who “would like show me like textbooks, like showing like, you know, transition fossils and that kind of thing.” Emily credits her family for her intellectual curiosity, which she related to her acceptance of evolution; Kate expressed a similar sentiment: “My parents always taught me science rather than other stuff.” Sasha discussed how their mother, a first-generation college student and biology major, exposed them to science from a young age by taking them to research conferences, and encouraging them on science fair projects. They concluded:

> …I think my upbringing definitely did have an impact. When you're not exposed to science as much or it's just not fun for you, then you get bored or you don't look at it as like a potential career. You're like, I would never do that. But I think that my personality and my upbringing kind of pushed me towards science. (Sasha)

Not surprisingly, family also influenced the interviewee’s religious views and their understanding of the interplay between science and religion. Coffee had no conflict, being raised in a Buddhist faith: “Well, my family… [t]hey're pretty religious… like they're, Buddhist. So that's their religion and they generally accept science and evolution itself. They don't really like say that it's wrong or like have any feelings against it. So because of that, I I didn't really grow up in a family that was against certain science ideas.” Individual One, a Lutheran, talked about how their father would take them to both church and the local science museum. Kate expressed how their parents preferred science to religion: “You know, I'm more of a scientific person rather than the religious aspect of it… My parents always taught me science rather than other stuff.” Penguin seemed to have the most complicated relationship of all. While their parents are not very religious, Penguin still seemed to have trouble reconciling their Jewish faith with evolutionary ideas:

> That's actually something I don't know. I don't know if they I mean, I just, you know, celebrated Passover with my family this weekend. And, you know, it was great, saw family members, got to go home. But I don't really know how, you know, what they truly believe in. I mean. I never really, never really got brought up. Yeah. So I don't really know how they think, but I kind of get the feeling that I kind of know. I kind of am getting a feeling of how they want me to think if that makes sense.
>
> I think it's a very unique aspect. I mean, they're not, you know, no.... no one really my family's overly religious… no one's like super religious. It's just that's the belief they were brought up with. And so they've stuck with it ever since. Just because there hasn't there hasn't been all these advances. You know, when they were in high school, when they were getting an education. So they're not– I wouldn't exactly say that they're overly religious. It's more of, you know, we celebrate the holidays. We do like our prayers and stuff. But I don't really know how much they really believe it and follow it. Like to what extent. I just know that I just don't really know how much science they believe.
>
> …I definitely have increased belief in evolution, but I guess the right word is I'm just afraid to let go of my religion because that's my upbringing and I don't want to disappoint my parents and family and… that's kind of like conflict.. Conflicting. (Penguin)

Of course, individuals’ religious views impact their acceptance of evolution more directly than their parents’ religious beliefs. This relationship is explored more in the following subsection.

Religion and evolution

As the above quote from Penguin shows, religious beliefs can be a tough barrier to evolution acceptance. Our interview subjects came from a variety of religious faiths, including Buddhism, Catholicism, Hinduism, Judaism, Lutheranism, and Pentecostalism, as well as individuals who expressed no religious preference. Some students expressed that they did not often attend religious services:

> …we don't go to church really? Ever. (Kate)

> …my family really isn't all that religious. (David)

but others were much more heavily involved in practicing their religious faiths:

> Yes, I go to church every Sunday. And I do Bible study once a week, sometimes even twice a week. And during like special occasions like Lent, holy week. I could be there like every day. …my faith ...has a lot of presence in my life. (Sasha)
> …my mom is really religious… we always went to church, or we still go to church and things like that. (Jenny)
> Yeah. So I actually do have a strong religious background. My whole family and I are Jewish. We've been practicing Judaism since I was born. We celebrate Shabbat every Friday. We were all Bar and Bat Mitzvahed. (Emily)

Students had differing views on the interplay between religion and evolution that did not fall along lines dependent on their religiosity. For example, contrast Emily and Penguin, two students of Jewish faith in the study. Emily says, "I have a strong identification with my religion, but I don't feel that it conflicts with evolutionary biology at all… I've never had an issue with the crossover between the two." In contrast, we saw above how Penguin felt that increasing their belief in evolution led to a fear of losing their religion, due to a "conflict", though they expected that they will "…never necessarily let go of one of them."

Sasha was another student who found no conflict between science and her religion, though she initially expected to:

> And I think some people think that when you go to college, it's gonna change. Oh, you're gonna be like fa– like your religion is gonna be like faced with the science part and you're going to be like questioning your religion because of the science that you're doing. But I think that everything has aligned. And what I've learned in biology not only makes sense, but also like aligns with what I believe. I think that just because, like you believe in God or have a religion doesn't mean you have to reject science.
> So I think there's still some space to to accept that, yes, evolution is true. And like animals with like through the centuries have changed into other organisms. But I don't think– there's no conflict in what I believe. (Sasha)

While there were lots of experiences in Sasha's life that may have seeded that expectation of conflict, they discussed having a professor in ninth grade who "…used to make fun of us like he– the ones that he knew were religious…. He used to say, oh, you don't have to study, just like pray three Hail Marys." Will specifically noted how this view of conflict is exacerbated by "popular atheists. Who... will discredit anyone who doesn't believe in what they believe by attacking their intelligence for not believing what they believe." Jenny further discussed how they found a balance between their religious and scientific views:

> I don't feel that conflict at all which I think can be kind of surprising because I feel like I think that people want you to choose. And I don't think there should be a reason why I have to choose. Like, why can't it be both? You know what I'm saying? Yes. Scientifically, this is how it happened. Perfect. But like, as someone who believes in God, why not say, OK, God started it here and then it just took off? Like, why can't I say that? Like, why are they not both... the same?
>
> You know, like you, you're understanding the process of life this- like this way, through types of experiments and tracing it back and that's beautiful. And like other people.. or I, I see that, I agree with you, and I also say, OK, well, then it started somewhere. Maybe God started it and then it kept going on. And I don't think I don't think either one of them is wrong, as long as you can see both.
>
> So like I... Thank God that my Catholic school was like, yeah, like this is evolution, here you go, you know, because imagine if they had said nope. Like, that was not it, like, what?! You know, I think you can. I think you can and should be able to accept both. And I don't think there's any conflict between that.
>
> Because they're giving you the same exact results. Ultimately, like, you know, whether whether you choose to believe that we came from a tiny cell or you choose to believe that God made you like. Either way, we're here now. So I think I don't have that conflict, personally.
>
> …And thankfully, like, I've never had anyone be like, nope, that's not how science works or that's not real or or anything like that because that would have been really like crushing. (Jenny)

Evolution as science

The final concept is that of how science influences acceptance of evolution. This theme was mostly derived from specific questions that asked students what aspects of the nature of science (phrased in more general terms) have influenced their, or might influence others', belief in evolution. Understanding of the nature of science has been shown to be one of the major things related to evolution acceptance (Dunk et al., 2019), including in the student population drawn on for this study that was surveyed in chapter two. Due to its less tangible nature, however, we expected this to be less likely to be noted by participants, so we made sure to question their views on it directly.

The main theme related to science that participants noted in relation to their acceptance of evolution was how science uses evidence to make its claims. Coffee summed up their views as such:

> Like, for me, those things are supported and are real because there is a lot of research that goes behind it. There's a lot of people that don't just like, make this up and that it's been tested and there are people who look into it even for things we can't see molecules and stuff that has been like. People have been working on it and they actually do research and they share that and it's been retested and it's been re– I guess, redone time and time again. (Coffee)

Jenny reiterated these ideas and added a specific mention of evolution:

> I think. I think before anyone takes you serious in science, you have to have a lot of research done and a lot of material to present. Like these are not like claims that came out of thin air. These are not concepts that are super, super new that we just decided yesterday that we were going to all be on board with this…
>
> I think you don't have to necessarily be like, evolution is a fact. 100 percent. But I feel like people should be like, I understand why you would think that. And I understand that like, the reason you guys came to this conclusion is not just a direct rejection of religion, but rather a conclusion you made off the evidence you have. (Jenny)

Penguin agreed, "I was just going to say it really comes down to evidence."

Coffee's quote above also shows how they consider testability to be an important part of scientific claims related to evolution. However, no other participants noted this directly. Other themes noted in the interviews that were limited to one or two participants were science being repeatable, creative ("I feel like you need to be able to have some form of creativity or be able to think of new ways or have new ideas about those fields, to push them forward,"– Aquafina), hands-on, and the idea of science as building (“Science builds. Science builds off of whatever we have in the past,”– Jenny).

3.4 Discussion

From both direct statements and the way students discussed evolution, it seems all individuals interviewed were quite accepting of evolution. This high level of evolution acceptance reflects that measured in chapter 2, which included these students in the sample population. High evolution acceptance levels like this are common in studies here, as reflected further in chapter 1 as well as previous studies at our university (Carter and Wiles, 2014).

The most discussed reason for individuals’ acceptance of evolution in this study was their high school experiences. This sometimes came in the form of teachers who were vocally supportive of evolution in addition to teaching the facts, but others only noted how learning about evolution led to their acceptance. In addition, none of the students who mentioned their teachers’ defense of evolution included any mention of the teachers discussing compatibility between religion and evolution. This is not surprising, given these were mostly public high schools, but this method (named the Religious Cultural Competence in Evolution Education, or ReCCEE method) has evidence that it may be among the best methods for improving students’ acceptance of evolution (Barnes and Brownell, 2017). This lack of inclusion reflects that many of these students likely did not have strong conflicting feelings between their religious views and scientific views (though we found some conflict, especially for Penguin), which led to acceptance through educational experiences without inclusion of conciliatory messages. Though the students did not specifically mention their knowledge of evolution as a reason for their acceptance, it seems that this discussion of their educational experiences is likely due, at least in part, to the knowledge gained in those courses. Knowledge of evolution is one of the major factors known to be related to evolution acceptance (Carter and Wiles, 2014; Cofré et al., 2017a; Dorner, 2016; Dunk et al., 2017; Glaze et al., 2015; Hawley et al., 2011; Mead et al., 2017; Rissler et al., 2014; Weisberg et al., 2018), so we did expect to find evidence of its impact in these students.

It has have shown that evolution acceptance in individuals can be related to aspects of their parents as removed as the level of education their parents receive (Barnes et al., 2019; Deniz et al., 2008), though this relationship does not always hold (Dunk et al., 2017; Glaze et al., 2015). Of course, family plays more direct impacts as well, as demonstrated in our results. Students mentioned their parents' views as having clear impacts on their views as well. Specifically, they discussed their parents' balance between religion and science. Again, we did not find this particularly surprising, though it is not something seen in quantitative studies often. This is likely due to the fact that the influence of parents describes the source of the students' views, but not necessarily the underlying psychological interaction that is the primary source of our interest. Qualitative studies in evolution acceptance have found similar results regarding the influence of parents on their children's evolution acceptance views (Borgerding et al., 2017; Donnelly et al., 2009; Wiles, 2014).

Religion is a major source of conflict for many individuals in their acceptance of evolution, with increased intensity of religious beliefs or practices associated with lower evolution acceptance (Borgerding et al., 2017; Carter and Wiles, 2014; Dunk et al., 2017; Glaze et al., 2015; Hawley et al., 2011; Miller et al., 2006; Rissler et al., 2014; Schleith, 2017; Weisberg et al., 2018; Wiles, 2014). While many of our participants were religious, they were still quite accepting. Some did, however, speak of the conflict they felt between their religious views and their scientific beliefs. Others, discussed the balance between the two that they found, though they did not currently see them as conflicting. We expected to see this in our participants, and were not too surprised by the lack of many with strong conflict, as that reflects our student population in general, and probably some additional selection bias. Most students in our study were able to balance their religion with the scientific facts without choosing ne over the other. This is important, as too often the prevailing view is of incompatibility. This leads to a situation where students feel forced to choose, and it is unlikely that students will forsake their religious views due to biology instruction. This is why recent work (also discussed above) has suggested that evolution instruction should include a small amount of discussion on compatibility between religion and evolution to reduce the perceived conflict students feel between evolution and religion (Barnes et al., 2017; Barnes and Brownell, 2017; Truong et al., 2018).

Finally, we asked students to discuss the interplay between their understanding of science and their acceptance of evolution. In general, students had difficulty discussing this topic, and did not often bring it up without specific prompting (in stark contrast to their discussion of religion or high school biology classes). When asked, students did discuss some ways that their science knowledge impacts their evolution acceptance, and this was mostly centered around their understanding of evidence as a key part of scientific claims. We were not surprised that students found this difficult to discuss, as it is more philosophical in some regards than the other topics which directly tie into students' lived experiences. However, we hoped that there would be more topics that students pointed to, especially as chapters 1 & 2 show that students' understanding of science as a unified body of knowledge was quite important (though the evidence discussed here might relate to the testable nature of science as discussed in those chapters). In general, the nature of science is recognized to be a major factor tied to acceptance of evolution (Dunk et al., 2019). We are hopeful the results here can add to that understanding, though it is clear more work needs to be done in understanding the relationship between acceptance of evolution and understanding the nature of science.

3.5 Conclusions

Our goal in this study was to use qualitative methods to explore in more detail the interaction between evolution acceptance and its known major cofactors, add nuance to our understanding of how those factors are related to acceptance of evolution, and learn more about how students conceive of their evolution acceptance and what influences they consider important in that acceptance. Overall, we succeeded on all these fronts. We found evidence that students' knowledge of evolution and religious practice influences their acceptance of evolution. With regards to the third major factor in evolution acceptance, understanding the nature of science, we found less evidence of students' considerations of the impact on their acceptance of evolution. This could be due to a lesser impact than we expected, but it is also possible that there is something less tangible about the nature of science that makes it less likely for students to notice its impact or be able to articulate it. In addition to the commonly recognized factors, we found that students commonly referred to their high school experiences in their acceptance of evolution. Certainly some of this is simply due to that being a strong educational influence, reflecting knowledge, but there is likely more reason than simply that. In previous qualitative studies of evolution acceptance this was a commonly discussed theme as well (Borgerding et al., 2017; Donnelly et al., 2009); those authors attributed some of the influence to an appeal to authority leading to acceptance. While some students answered in ways consistent with that, it is clear that the influence of high school teachers on these students' evolution acceptance is more complex than a simple authoritative belief.

These results suggest two important avenues for further exploration. First, more work should be done to explore the influence high school teachers have on their students' evolution acceptance, as it is a common theme even for students in their second and third year of university education. It is well known that high school teachers influence their students' acceptance of evolution (Moore and Cotner, 2009), and indeed a large amount of the evolution education literature has focused on pre-service and in-service high school biology teachers for this very reason (Akyol et al., 2012; Berkman and Plutzer, 2010; Cofré et al., 2017a; Deniz, 2011; Glaze et al., 2015; Nehm et al., 2009; Rutledge and Warden, 2000). Future studies can focus on the interplay between informational transfer and role model/ authority that high school teachers likely play in influencing their students' evolution acceptance and related views. Second, while students were able to articulate how their acceptance of evolution was influenced by the use of scientific evidence, they did not consider some of the less tangible influences of the complex nature of science found to be significantly related to acceptance of evolution. Further work on understanding this relationship should seek to include qualitative explorations that probe participants' understanding of the relationship further, perhaps starting with think-aloud interviews of the measure(s) of understanding the nature of science used.

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Conclusion

In this dissertation, I set out to confirm previous studies documenting variables associated with the acceptance of evolution in college students while expanding the population surveyed, adding a longitudinal time frame, refining the measures used, and adding a qualitative component to the research agenda. The three chapters combined do that, and form a cohesive story that adds greatly to our understanding of evolution acceptance in general, and more specifically here at Syracuse University. We found that acceptance of evolution in our students is primarily, but not exclusively, associated with their knowledge of evolution, religiosity, and understanding of the nature of science. This is in line with many recent studies on evolution acceptance (Barnes et al., 2019; Dunk et al., 2017; Glaze et al., 2015), and helps add to the growing consensus that these variables form the core of the model of acceptance of evolution (Dunk et al., 2019; Pobiner, 2016).

In chapter one, we studied evolution acceptance across a year of instruction in introductory biology. We analyzed two linear models, one run on data collected from the beginning of the year and one run on data collected from the end of the year. There were some variables that differed between these two models. In fall, we found that an understanding of science as amoral and unified had a significant relationship with acceptance of evolution, but understanding science as testable did not have the same impact. In spring it was an understanding of science as unified and testable that had the significant impact, and understanding science as amoral was no longer significant. Similarly, while an individual's intrinsic religiosity was significantly associated with their evolution acceptance throughout the year, their religious affiliation ("denomination") was only significantly related in the fall, and their number of religious friends was only significant in the spring. Finally, we noted that the number of college biology classes taken was significantly associated with evolution acceptance in fall, but after a year of instruction, this prior exposure was no longer related.

We then looked at paired data across the year and measured individual students' changes in their acceptance of evolution and changes in the other numeric variables. We found that, similarly to the linear models, change over the year in evolutionary knowledge, genetic literacy, intrinsic religiosity, and an understanding of science as amoral, unified, and testable were significantly associated with change over the year in evolution acceptance. Some additional variables were related as well, but as they were only significant in the individual change regressions and not the linear models they are not likely as important for future study.

In chapter two, we expanded our survey population to investigate which of the same variables in chapter one were significantly associated with evolution acceptance in a general population of undergraduates. We surveyed students at the beginning and end of their first semester on campus, as part of their first year experience course. This allowed us to determine if the results seen in chapter one have generalizability to college students in general. Due to the significance of religiosity in our results from chapter one, we also modified our measure of religiosity to one that measured both intrinsic (value of religion is in personal meaning and understanding) and extrinsic (value of religion is in community and protection during hard times) aspects of religiosity.

In this chapter, we only used the measures of normalized change over the semester for our analyses. First, we analyzed each variable's individual regression on normalized change in acceptance of evolution, and found that normalized change in an understanding of science as testable, an understanding of science as unified, evolutionary knowledge, genetic literacy, intrinsic and extrinsic religiosity, and openness to experience (a personality measure associated with intellectual curiosity) all had significant relations with normalized change in acceptance of evolution. We then put all these terms in a stepwise regression model, and found that normalized change in the acceptance of evolution was significantly *and independently* related to normalized change in understanding science as unified, evolutionary knowledge, and intrinsic religiosity, confirming the results from chapter one. We also found that change in genetic literacy had a significant relationship in the initial model, but it was in the opposite direction expected: increasing genetic literacy over the semester led to decreased acceptance of evolution in these students. Running the model with an expanded sample found this relationship was no longer significant, though it still maintained its negative association. This negative relationship was very unexpected and does not agree with any previous studies analyzing the relationship between genetics understanding and evolution acceptance (Hawley et al., 2011; Mead et al., 2017; Miller et al., 2006), including that in chapter one.

Genetic literacy notwithstanding, chapter one and two overall agree very well, showing that, at least at Syracuse University, students on average have similar reasons for their acceptance or rejection of evolution, regardless of their enrollment in biology. In these studies, the linear models tend to explain around 40% of the variance seen in acceptance of evolution. While this is quite good for a study that is attempting to explain variation in human psychological processes, it still means that the majority of variation in evolution acceptance seen is not related to the survey measures used. Thus, more general investigation into individuals' acceptance of evolution is warranted.

Chapter 3 approached this problem by taking a qualitative approach to exploring evolution acceptance in the same population as chapter 2. In this chapter, we interviewed students who responded to our call for follow-up interviews. We allowed students to explain for themselves the reasons behind their acceptance of evolution, though we prompted with questions related to the factors that were identified to be related to evolution acceptance in chapter 2. Our goal in taking this approach was not only to find possible reasons for evolution acceptance that we did not consider in our surveys; in fact, the main reason was to add additional detail and nuance to our understanding of the variables currently known to be associated with acceptance of evolution.

For the most part, we found student responses were in line with the results seen in chapters 1 & 2. Religion and religious views factor heavily in these students' understanding of their acceptance of evolution. Students discussed the balance they find between their religious views and evolution. For some, this was a delicate balancing act, but others found no conflict between their religious views and evolution. Others still were not religious and were not concerned about religious impacts on their acceptance of evolution. Students also described how their knowledge of evolution impacted their acceptance. This discussion, however, focused primarily on students' high school experiences in biology courses, not on specific information that students found compelling about evolution. Lastly, students did not freely offer a description about how their acceptance of evolution was impacted by their understanding of science. When asked, participants mostly discussed how scientific claims like evolution are based on evidence. Using qualitative methods reaffirmed the primary variables associated with evolution acceptance as found in chapters 1 & 2. However, this different style of analysis allowed us to investigate some of the reasoning behind those associations, and hear students' personal conceptions behind their evolution acceptance.

Together, these three chapters complement each other and verify the results seen in other recent studies of evolution acceptance. Evolution acceptance is related to many things, but it seems to be most strongly and consistently related to knowledge of evolution, religious views, and understanding of the nature of science. This is true across studies in varied geographical places and institution type (Barnes et al., 2019; Dunk et al., 2017; Glaze et al., 2015). This dissertation extends that to show that it is also true across time, and in a general student population. Further, it adds additional nuance to the discussion via the explanatory mixed methods design implemented across the second and third chapters.

Future work can extend on these findings in a number of ways. Most notably, the finding of the importance of nature of science highlights the need for effective measurement of the nature of science. This work attempted to do that by using the NSKS measure, but that alone is insufficient. Further work should focus directly on the effect of nature of science on evolution acceptance, using both survey measures and careful, pointed interviews. Additionally, my colleagues and I noted the need in evolution education for studies that explore more closely evolution education in groups that have been traditionally marginalized in STEM (Dunk et al., 2019). This strategy has found much success in other realms of biology education, but has not yet been applied much to evolution education. If our goal in increasing acceptance is to help ensure our students are successful in their biology studies, it is important that the strategies we recommend have at least equal effect for all, if not special benefit to those traditionally overlooked in science.

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Walls L. Awakening a dialogue: A critical race theory analysis of U. S. nature of science research from 1967 to 2013. J Res Sci Teach 2016;53:1546–70. https://doi.org/10.1002/tea.21266.

Weisberg DS, Landrum AR, Metz SE, Weisberg M. No missing link: Knowledge predicts acceptance of evolution in the United States. BioScience 2018;68:212–22. https://doi.org/10.1093/biosci/bix161.

Wiles JR. Gifted students' perceptions of their acceptance of evolution, changes in acceptance, and factors involved therein. Evol Educ Outreach 2014;7:4.

Wiles JR, Alters B. Effects of an educational experience incorporating an inventory of factors potentially influencing student acceptance of biological evolution. Int J Sci Educ 2011;33:2559–85. https://doi.org/10.1080/09500693.2011.565522.

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Zuur AF, Ieno EN, Elphick CS. A protocol for data exploration to avoid common statistical problems: Data exploration. Methods Ecol Evol 2010;1:3–14. https://doi.org/10.1111/j.2041-210X.2009.00001.x.

Curriculum Vitae

Ryan Disney Patrick Dunk
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EDUCATION

Ph.D. Syracuse University (Biology) 2020
Thesis: "Evolution Acceptance, Religiosity, and Nature of Science in an Undergraduate Population" Thesis Advisor: Jason Wiles
Certificate in University Teaching, Future Professoriate Program *2019*

M.S. University of Wisconsin – Milwaukee (Biological Sciences) 2013
Thesis: "Seasonality of Conceptions Under Varying Conditions in a Rhesus Macaque Breeding Colony" Thesis Advisor: A.J. Petto

B.S. University of Wisconsin – Parkside 2009
(Biological Sciences, Summa Cum Laude)

RESEARCH EXPERIENCE

Syracuse University Biology Education Research Group, Syracuse University 2015 – 2020

Doctoral Dissertation Research in Evolution Acceptance, PI Jason Wiles

Conducted quantitative and qualitative analysis around three main themes in biology education. Linear modeling was used in multiple distinctive undergraduate populations to determine factors affecting students' acceptance of evolution, and how both acceptance and related factors change over time. Additionally, interviews were used to add a qualitative investigation into how students perceived their acceptance of evolution. To date, this work has led to 2 first authored manuscripts and over 10 conference presentations.

Active Learning Research in Introductory Biology Classrooms, PI Jason Wiles

Various methods were used to determine the efficacy of peer-led team learning, with an emphasis on how this active learning strategy leads to specific benefits for students underrepresented in biology such as first-generation college students and members of underrepresented racial and ethnic minorities. Additionally, my lab mate and I investigated the impact of early primary literature exposure on freshman students' nature of science conceptions. To date, this work has led to 3 published or submitted manuscripts and 8 conference presentations.

Anti-Christian Bias in Biology, PI Jason Wiles

An undergraduate advisee and I used qualitative methods to investigate Christian students' perceptions of bias in biology courses and their persistence in the major.

This work has led to a conference presentation and has a manuscript in preparation (early draft, senior authorship).

Center for Reproductive Evolution, Syracuse University 2017

Graduate Research Experience, PIs Scott Pitnick & Steve Dorus

Measured copulation duration times in over 20 species of *Drosophila*, maintained fly stocks, and measured egg size variables using ImageJ software. Led to second-authored manuscript (in prep).

Department of Anthropology, University of Wisconsin – Milwaukee 2013 – 2015

Graduate Research Experience, PI Ben Campbell

Conducted survey and used linear modeling to analyze factors affecting students' acceptance of evolution. Led to a first-authored manuscript and multiple conference presentations.

Department of Biological Sciences, University of Wisconsin – Milwaukee 2009 – 2013

Master's thesis research, PI Anj Petto

Digitized 25+ years of breeding records from Harvard's New England Primate Research Center. Used linear modeling to analyze cyclical yearly patterns of reproductive fecundity in rhesus macaques; compared yearly fecundity cycles across housing treatments to determine the effects of environmental variables. Research assistantship in 2012; led to a first-authored manuscript and conference presentation.

Department of Biological Sciences, University of Wisconsin – Parkside 2009

Undergraduate research, PI Bob Sasso

Identified prehistoric stone tool artifacts by type and culture. Led to poster at university symposium.

Department of Biological Sciences, University of Wisconsin – Parkside 2007 – 2008

Undergraduate research, PI Scott Thomson

Conducted various small experiments and experiences involving *Tribolium*.beetles.

GRANTS

Mixed Methods Grant Obtaining Operational Development (MMGOOD), Collaboration for Unprecedented Success and Excellence (CUSE) Seed Grant (co-author with PIs Jason Wiles and Rebecca Schewe); **$4,960** 2018 – Present

Rosemary Grant Graduate Student Research Award, Society for the Study of Evolution; **$2,492** 2017

Unfunded: A Longitudinal, Explanatory Mixed Methods Inquiry into the Acceptance of Evolution, Sigma Xi Grants-in-Aid of Research (2018, $1,000); Doctoral Research: Conceptual, Educational, and Personal Change in Early University Experience, NSF SES Science, Technology, & Society Doctoral Dissertation Improvement Grant (2017; $14,936); Doctoral Dissertation Research: Conceptual, Educational, and Personal Change in Early University Experience, NSF SES Sociology Doctoral Dissertation Improvement Grant (2017; $11,996)

Honors and Awards

Summer Dissertation Fellowship, Syracuse University Graduate School — 2019

Carlock Award for Excellence in Graduate Student Research, Association of College and University Biology Educators — 2016, 2018–19

Outstanding T.A. Award, Syracuse University Graduate School — 2018

First Year Student Success Award, University of Wisconsin – Milwaukee — 2012

Chancellor's Award, University of Wisconsin – Milwaukee — 2009 – 2011

Provost's List, University of Wisconsin – Parkside — 2005 – 2009

Irene Laning Scholarship, University of Wisconsin – Parkside — 2005 – 2009

National Science Foundation S-STEM Scholarship/ UWP Science Scholars Program, University of Wisconsin – Parkside — 2008

Travel awards (Society for the Study of Evolution 2016–17, 2019; Syracuse University Biology Department 2016–17, 2020; Syracuse University Graduate Student Organization 2017–2020) — Various

Publications

Peer-reviewed

9. Romine, W, **RDP Dunk**, R Mahajan, and A Todd. Measuring Science Teachers' Emotional Experiences with Evolution using Real World Scenarios. *Science Education (in revision).*

8. Sloane, JD, **RDP Dunk**, JJ Snyder, CI Winterton, KM Schmid, and JR Wiles. Peer-Led Team Learning improves minority student retention in STEM majors. *PLoS One (in revision).*

7. **Dunk, RDP**, and JR Wiles. Changes during a year of introductory biology on acceptance of evolution and associated factors. *Journal of Research in Science Teaching (in review).* preprint: https://www.biorxiv.org/content/early/2018/03/13/280479

6. Schmid, KM, **RDP Dunk**, and JR Wiles. Early exposure to primary literature and interactions with scientists influences novice students' views on the nature of science. *Journal of College Science Teaching (Accepted, in press).*

5. Winterton, CI, **RDP Dunk**, and JR Wiles. 2020. Peer-Led Team Learning for introductory biology: Relationships between peer-leader relatability, perceived role model status, and

the potential influences of these variables on student learning gains. *Disciplinary and Interdisciplinary Science Education Research* 2:3. doi: 10.1186/s43031-020-00020-9

4. **Dunk, RDP**, ME Barnes, MJ Reiss, B Alters, A Asghar, BE Carter, S Cotner, AL Glaze, PH Hawley, JJ Jensen, LS Mead, LS Nadelson, CE Nelson, B Pobiner, EC Scott, A Shtulman, GM Sinatra, SA Southerland, EW Walter, SE Brownell, and JR Wiles. 2019. Evolution education is a complex landscape. *Nature Ecology and Evolution* 3:327-329. doi: 10.1038/s41559-019-0802-9

3. **Dunk, RDP**, AJ Petto, JR Wiles, and BC Campbell. 2017. A multivariate analysis of acceptance of evolution. *Evolution: Education and Outreach* 10:4. doi:10.1186/s12052-017-0068-0

2. Snyder, JJ, JD Sloane, **RDP Dunk**, and JR Wiles. 2016. Peer Led Team Learning helps minority students succeed. *PLoS Biology* 14:e1002398. doi:10.1371/journal.pbio.1002398

1. **Dunk, RDP**, AJ Petto, GC Mayer, and BC Campbell. 2015. Seasonality of conceptions in captive rhesus macaques (*Macaca mulatta*). *International Journal of Primatology*, 36:855-870. doi:10.1007/s10764-015-9858-9

Non-refereed

2. **Dunk, R.** 2017 Sep 11. A good understanding of the "nature of science" is what most facilitates acceptance of evolution. SpringerOpen Blog (published concurrently with a different title on BioMed Central). http://blogs.springeropen.com/springeropen/2017/09/11/a-good-understanding-of-the-nature-of-science-is-what-most-facilitates-acceptance-of-evolution/ *(Invited blog post to highlight recently published paper)*

1. **Dunk, R.** 2017. Human Evolution. *The American Biology Teacher* 79:598-599. *(Book review)*

CONTRIBUTED PRESENTATIONS (*presenting author; ^ undergraduate author)

29. **Dunk, RDP***, and JR Wiles. Students' perspectives on their acceptance of evolution. Talk, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2020 (*submitted, in review*)

28. Pepi, MC^*, JR Wiles, and **RDP Dunk**. Religious Students' Perceptions in Biology. Talk, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2020 (*submitted, in review*)

27. **Dunk, RDP***, and JR Wiles. Students' perspectives on their acceptance of evolution. Talk, National Association for Research in Science Teaching, Portland, OR; March 2020 (*accepted, conference canceled*)

26. **Dunk, RDP***, and JR Wiles. An Investigation into the Factors Influencing Acceptance of Evolution across University Instruction. Poster, National Association for Research in Science Teaching, Portland, OR; March 2020 (*accepted, conference canceled*)

26. Pepi, MC^*, JR Wiles, and **RDP Dunk***. Factors affecting Christian students' persistence in STEM. Poster, Association of College and University Biology Educators, Syracuse, NY; October 2019

25. **Dunk, RDP***, and JR Wiles. Five years of evolution acceptance – Are general students different than biology students? Talk, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2019

24. Grunspan, DZ*, **RDP Dunk**, JR Wiles, ME Barnes, and SE Brownell. Testing the effect of human examples when teaching evolution. Talk, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2019

23. **Dunk, RDP***, and JR Wiles. Yearlong changes in evolution acceptance in a general student cohort. Talk, Evolution 2019, Providence, RI; June 2019

22. **Dunk, RDP***, and JR Wiles. Five years of evolution acceptance– How do general students differ from biology students? Poster, Evolution 2019, Providence, RI; June 2019

21. **Dunk, RDP***, and JR Wiles. Changes in Acceptance of Evolution and Associated Factors during a Year of Introductory Biology. Roundtable paper, American Educational Research Association, Toronto, ON; April 2019

20. **Dunk, RDP***, and JR Wiles. Five years of evolution acceptance – Are general students different than biology students? Talk, National Association for Research in Science Teaching, Baltimore, MD; March 2019

19. Schmid, KM, **RDP Dunk***, and JR Wiles. The effects of an introduction to biological research course on novice students' views on the nature of science. Talk, Association of College and University Biology Educators, Milwaukee, WI; October 2018

18. **Dunk, RDP*** and JR Wiles. Comparative Confirmatory Factor Analyses of Measurement Traits between Intended Biology Majors and other First Year College Students. Talk, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2018

17. Schmid, KM*, **RDP Dunk**, and JR Wiles. The effects of an introduction to biological research course on novice students' views on the nature of science. Talk, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2018

16. Winterton, CI, **RDP Dunk***, and JR Wiles. Peer Leaders as Potential Role Models and the Impact on Perceived Student Learning Gains. Poster, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2018

15. Cannon, I^, **RDP Dunk**, KM Schmid, MC Pepi^*, JJ Snyder, JR Wiles. Peer-Led Team Learning May Decrease Impostor Feelings. Poster, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2018

14. **Dunk, RDP*** and JR Wiles. Changes During a Year of Introductory Biology on Acceptance of Evolution and Associated Factors. Talk, National Association for Research in Science Teaching, Atlanta, GA; March 2018

13. **Dunk, RDP**, and JR Wiles*. The Impact of Changes in Factors on Evolution Acceptance During a Year of Introductory Biology Instruction. Talk, Association for College and University Biology Educators, Columbia, SC; October 2017

12. **Dunk, RDP***, and JR Wiles. The Impact of Changes in Factors on Evolution Acceptance During a Year of Introductory Biology Instruction. Talk, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2017
11. Wiles, JR, JJ Snyder, JD Sloane, **RDP Dunk***, and CI Winterton. Peer-Led Team Learning and STEM Achievement, Recruitment, and Retention for Underserved Groups. Poster, Society for the Advancement of Biology Education Research, Minneapolis, MN; July 2017
10. **Dunk, RDP***, and JR Wiles. Changes in Acceptance of Evolution and Associated Factors During a Year of Introductory Biology Instruction. Poster, Evolution 2017, Portland, OR; June 2017
9. Sloane, JD, JJ Snyder, **RDP Dunk***, CI Winterton, and JR Wiles. The Influence of Peer-Led Team Learning on the Recruitment and Retention of Underrepresented Minority Students in STEM Majors. Talk, National Association for Research in Science Teaching, San Antonio, TX; April 2017
8. **Dunk, RDP***, AJ Petto, and BC Campbell. A multifactorial analysis of the acceptance of evolution in college students. Poster, National Association of Biology Teachers, Denver, CO; November 2016
7. Sloane, JD*, JJ Snyder, **RDP Dunk**, CI Winterton, and JR Wiles. PLTL Enhances Retention in STEM Majors among Women and First-Generation College Students. Poster, National Association of Biology Teachers, Denver, CO; November 2016
6. **Dunk, RDP***, AJ Petto, and BC Campbell. A multifactorial analysis of the acceptance of evolution in college students. Talk, Association of College and University Biology Educators, Milwaukee, WI; October 2016
5. **Dunk, RDP***, and JR Wiles. The impact of geographic origin on acceptance of evolution in college students. Poster, Association of College and University Biology Educators, Milwaukee, WI; October 2016
4. Sloane, JD*, JJ Snyder, **RDP Dunk**, CI Winterton, and JR Wiles. PLTL Enhances Retention in STEM Majors among Women and First-Generation College Students. Talk, Association of College and University Biology Educators, Milwaukee, WI; October 2016
3. **Dunk, RDP***, BC Campbell, and AJ Petto. A multifactorial analysis of the acceptance of evolution in college students. Talk, Evolution 2016, Austin, TX; June 2016
2. **Dunk, RDP***, GC Mayer, and AJ Petto. Heritability of a fitness-related trait in a captive population of rhesus macaques (*Macaca mulatta*). Talk, Central States Anthropological Society 2014, Normal, IL; April 2014
1. **Dunk, RDP***, KM Smith, and R Sasso. An analysis of prehistoric stone artifacts from the Lorence Farm site in Caledonia, WI. Poster, University of Wisconsin – Parkside Showcase of Student Scholarship, Kenosha, WI; May 2009

INVITED PRESENTATIONS

Syracuse University, Future Professoriate Program Annual Conference 2019

California State University, Fresno, Department of Biology 2019

Syracuse University, Department of Biology 2016 – 2019

PROFESSIONAL DEVELOPMENT

Invited participant, "Science Education Research in Disciplinary Contexts", Sandra K. Abell Institute for Doctoral Students, Middle Tennessee State University 2019

Presenter and Attendee, Future Professoriate Program Annual Conference, Syracuse University 2019

Invited participant, "Finding Bounty and Balance at a Comprehensive University" High-Impact Practices Bootcamp, California State University, Fresno 2018

Attendee, Future Professoriate Program Annual Conference, Syracuse University 2018

TEACHING EXPERIENCE

Graduate Teaching Assistant, Biology, Syracuse University 2020

General Biology II

- Taught active learning activities during introductory biology lecture time
  - ¼ of total course time for full semester
  - Core intro course for biology majors, gen ed course for nonmajors
- Pedagogies used: TurningPoint clickers, case studies, worksheets

Instructor, Biology, Syracuse University 2019

Ecology & Evolution

- Instructor of record, co-taught with Dr. Katie Becklin
- Taught evolution portion of course
- Core course for biology majors
- Pedagogies used: TurningPoint clickers, case studies, write to learn

HHMI Inclusive Excellence Active Learning Fellow,
Biology, Syracuse University 2018 – 2019

- Teaching fellow
- Taught active learning activities during lecture time of General Biology I and II
  - Core intro course for biology majors, gen ed course for nonmajors
  - ¼ of total course time for full year
- Assisted with development and implementation of case studies in Ecology & Evolution (majors core course)
- Pedagogies used: TurningPoint clickers, case studies, worksheets

Graduate Teaching Assistant, Biology, Syracuse University 2015 – 2018

General Biology I and II

- Instructor of record
- Taught integrated laboratory and recitation sections
- Core intro course for biology majors, gen ed course for nonmajors

Graduate Teaching Assistant,
Anthropology, University of Wisconsin–Milwaukee 2013 – 2015

Introduction to Anthropology: Culture and Society

- Taught discussion sections and assisted in lecture course management
- Introductory cultural anthropology course for majors and nonmajors

Instructor, Art History and Sciences, Milwaukee Institute of Art and Design 2013 – 2015

Introduction to Natural Science: Biology

- Instructor of record
- Taught integrated lecture and laboratory course
- Required course for all students, none majors
- Promoted from adjunct professor to instructor, 2014

Graduate Teaching Assistant,
Biological Sciences, University of Wisconsin–Milwaukee 2009 – 2013

Anatomy and Physiology I

- Taught laboratory sections
- Introductory human anatomy course for majors

Human Structure and Function

- Taught laboratory sections
- Introductory human anatomy course for nonmajors

Plants in Today's World

- Taught laboratory sections
- Introductory plant biology course for nonmajors

SERVICE TO THE DEPARTMENT AND UNIVERSITY

Biology Graduate Student Organization, Syracuse University 2016 – Present

Social Committee Representative (Chaired 2018 – 19) 2017 – Present
Graduate Representative to Departmental Graduate Recruitment Committee 2018 – 2019
Vice President 2017 – 2018
Graduate Representative to Departmental Curriculum Committee 2016 – 2017

Summer Undergraduate Research Forum Co-organizer (2018 – 19) and presenter, Biology Department, Syracuse University 2017 – 2019

Graduate Development Committee, Biology Department, Syracuse University 2016

Graduate Student Advisory Council, Special Projects Subcommittee, University of Wisconsin – Milwaukee 2014

SERVICE TO THE PROFESSION

Proposal Reviewer for Annual Meeting, Society for the Advancement of Biology Education Research 2017 – 2019

Social Media Chair, Association of College and University Biology Educators 2018 – 2020

Program Chair, 2019 Meeting of the Association of College and University Biology Educators 2019

Proposal Reviewer for Annual Meeting, National Association of Research in Science Teaching 2018 – 2019

COMMUNITY SERVICE AND OUTREACH

BGSO Outreach, Westcott Community Center After-School Kids Club 2017 – Present

Judge, Environmental Challenge 2018 Science Fair, State University of New York – Environmental Science and Forestry and Syracuse City School District 2018

Judge, Rochester Science Congress 2016

Judge, UW System Symposium for Undergraduate Research & Creative Activity 2014

JOURNAL AFFILIATIONS

Ad Hoc Reviewer: *American Biology Teacher, Bioscene, Integrative & Comparative Biology,* and *Journal of Research in Science Teaching*

PROFESSIONAL AFFILIATIONS

American Educational Research Association
Association of College and University Biology Educators
National Association of Research in Science Teaching
National Science Teachers Association
Sigma Xi
Society for the Advancement of Biology Education Research
Society for the Study of Evolution

ADVISING

Undergraduate Researchers

Mia Pepi, Syracuse University 2018 – Present

Isabella Cannon, Syracuse University 2017 – 2018