

UNDERGRADUATE MISCONCEPTIONS OF EVOLUTIONARY PRINCIPLES:

A COMPARATIVE STUDY

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Abstract: The theory of evolution and its role in the origin of human beings is a highly controversial and polarizing topic in the United States. More so, how evolution is taught in high schools is a hot topic of debate between school board members, parents, scientists, and science advocates. Historically, Texas Board of Education has repeatedly had issues regarding how much time the curriculum allots for evolution as well as controversial wording on how evolution should be explained to students. While it is unconstitutional to teach creationism in public schools, the lack of clear evolution education has allowed high school students to adopt misconceptions regarding evolution and the nature of science. These misconceptions can carry over to a student's undergraduate education, potentially making it more difficult for students to grasp biological concepts. In 2009, Drs. Deborah Cunningham and Daniel Wescott published a study on University of Missouri-Columbia undergraduates' comprehension of evolution. They found that while most of the students surveyed supported the theory of evolution, they had a limited understanding of evolutionary concepts (Cunningham and Wescott 2009). In this research project, Dr. Cunningham and Wescott's survey was recreated at Texas State University in San Marcos. The survey was administered at the beginning of the 2019 Fall semester to a Biological Anthropology class. It was found that participants' level of understanding did not differ much from the results found in 2009. While most participants reported understanding and supporting evolutionary theory, several notable misconceptions within the class were discovered. In addition, students were asked to provide what high school they attended and to report if they were taught evolution in high school. The schools were then plotted for the analysis of geographical trends.

Part I: Introduction

Evolution Education in the United States

Since the synthesis of the modern evolutionary theory, there has been a complicated relationship with the American public, especially within the education system. The ongoing battle for proper education standards has led to many court cases and the passing of laws, some of which excluded evolution from curriculums entirely. One law passed in Tennessee completely barred the teaching of any theory that contradicted the divine creation of mankind outlined in the Bible (*Butler Act 1925*). This led to the famous “Monkey Trial” of 1925, in which Tennessee science teacher John Scopes was prosecuted for teaching human evolution. Scopes was found guilty of teaching of violating state law, and was restricted to teaching the topics deemed appropriate by the state (Hall 2018). Evolution was effectively removed from American public schools until the middle of the twentieth century, when pressures associated with the Cold War resulted in a nation-wide campaign for scientific advancements (Berkman & Plutzer 2010). This new focus on science, along with newly accumulated evidence supporting evolution, led to the theory being included in textbooks. However, many states still had laws against books that advanced the theory of evolution. As more court cases emerged, some of which advanced all the way to the Supreme Court, a shift in focus on the First Amendment’s establishment clause became evident (Hall 2018). This states that the US government cannot advocate for a religious establishment. This shift opened the door for evolution to become a standard in classrooms, as previous objections to evolution education were based on religious beliefs (Berkman & Plutzer 2010).

This shift came to a head in 1982, in which the *McLean v. Arkansas Board of Education* case ruled that “creation science” was a justification of bringing biblical doctrine into public school classrooms (Hall 2018). Similarly, in 1987, the United States Supreme Court ruled that teaching creationism in public schools was unconstitutional (*Edwards v. Aguillard*) after Louisiana legislature passed the “Balanced Treatment for Creation-Science and Evolution-Science Act,” otherwise known as the “Creation Act” (Brown 2014). This act didn’t require creationism or evolution to be taught in schools, but it mandated that if one ideology were to be taught, the other had to be as well. Although teaching creationism is unconstitutional, the remnants of this long battle for evolution is still seen in classrooms today. Because this topic is still controversial among the public, and because how educators teach evolutionary theory isn’t heavily regulated, teachers can often include creationism into their lesson plans, or disregard evolution entirely. While consistent polling within the last few decades has shown that around one-third to one-half of Americans deny the validity of the theory of evolution (Wiles 2010), evolution has been nearly unanimously agreed upon by scientists.

When it comes to teaching this topic to high school students in Texas, many science teachers and advocates have concluded that the Texas Board of Education has failed to achieve adequate evolution standards. The Texas Essential Knowledge and Skills curriculum does not concretely state how much time should be dedicated to evolution, and also includes controversial wording in regard to how evolutionary concepts should be explained to students (Ayala 2017). Specifically, the word “evaluate” is used repeatedly when describing how evolution should be taught, which many science advocates view as a loophole to introduce creationism to students (Ayala 2017).

Furthermore, even when evolution is taught, the explanations can be unclear and students are often left confused and vulnerable to adopting many misconceptions about the it. These misconceptions can carry over to a student's undergraduate education, making it more difficult for them to grasp complex biological concepts. College students often come to their science classes already influenced by the misconceptions they learned earlier in life, whether from high school classrooms or elsewhere. Because of this issue, a university student may find it difficult to understand science concepts, even when the explanations are accurate and presented in a clear way.

2009 Survey

There have been numerous studies that have demonstrated the frequent misconceptions that college-level students hold regarding the theory of evolution and nature of science. In 1988, just a year after the Supreme Court ruled teaching creationism unconstitutional, Alan Almquist and John Cronin published their 10-year study on college students' understanding of evolution. They concluded that students' understanding of evolutionary theory and other scientific concepts are in drastic need of improvement (Almquist and Cronin 1988). Studies done since then have also generated similar conclusions: that college students, and Americans in general, demonstrate a significant level of scientific illiteracy and a high support of "intelligent design," or theistic explanations for the origins of life (Newport 2004; Coyne 2005). Even if a student does support evolution over creation, misconceptions regarding the mechanics of evolution are very common; these misconceptions may be self-constructed, learned in classroom setting, or learned throughout life experience (Alters and Nelson 2002).

In 2009, Drs. Deborah Cunningham and Daniel Wescott surveyed 547 undergraduate students enrolled in an introductory biological anthropology course at the University of Missouri-Columbia to identify and analyze the misconceptions students held regarding evolutionary theory (Cunningham and Wescott 2009). Their participants were enrolled in Introduction to Biological Anthropology during Fall 2002, Fall 2003, and Winter 2003. In this study, Cunningham and Wescott's survey was applied to students at Texas State University (TXST).

Part II: Methods

To identify and evaluate the perceptions and misconceptions held by undergraduates concerning evolutionary theory, the anonymous survey was distributed to a Biological Anthropology class during the usual lecture time. Due to scheduling issues, the survey was not administered until the 3rd day of class. Ideally, the survey would have been administered on the first day of class to prevent any content learned in the course from influencing the responses of participants. However, as further examined in the Discussion portion of this study, the delay in the survey is not thought to have had much of an influence on participant responses. Because it was necessary for the survey to be optional, an alternative activity for students who did not wish to participate was required. To fulfill this requirement, a simple crossword puzzle was provided for students at the end of their survey packet. The survey was kept completely anonymous and was approved by the Texas State Internal Review Board.

The questionnaire was divided into two sections: a portion dedicated to background information of the participant, and a series of 24 statements designed to test the participants' understanding of the process of evolution and the nature of science. The

requested background information included age, sex, classification, major, high school attended, and how or if they were taught evolution in high school. The goal of acquiring background information is create a general profile of the students being surveyed, in addition to further examining if certain parameters significantly influence the attitudes an individual might have towards evolution. Following the background information portion of the questionnaire were 24 general statements designed to examine the participants' understanding of evolutionary theory and understanding of science. The statements used were originally published in Cunningham and Wescott's 2009 study of undergraduates at the University of Missouri-Columbia (Cunningham and Wescott 2009). For these questions, the participants were asked to respond on a score from 1-5, with 1 meaning "strongly agree," 2 meaning "somewhat agree," 3 meaning "somewhat disagree," 4 meaning "strongly disagree," and 5 meaning "undecided/no opinion."

Selection of Participants

The survey was administered to 173 undergraduate students at TXST enrolled in Biological Anthropology during the Fall 2019 semester. Biological Anthropology is typically a very large class, with a maximum enrollment of nearly 400 students. Because Biological Anthropology fulfills the Life and Physical Sciences Component Code 030, the educational backgrounds and majors of enrolled students often vary. While this is a required course for all anthropology majors, less than a quarter of the students enrolled were anthropology or science majors (Table 1). The remaining participants that were non-science and non-anthropology majors were expected to have limited background knowledge of scientific concepts. Because evolutionary theory is a key component to this

course, students are expected to gain a clear understanding of evolution, natural selection, variation, and how these components fit into human evolutionary history.

It is important to note that while 173 students were surveyed, only 169 surveys were used in the data analysis. To be included in the data analysis, a questionnaire had to have a fully complete background section, and at least 50% of the questions answered. Four participants failed to meet this standard, and were subsequently removed from the data set (see Discussion).

Table 1. Student Profile

Demographic Variable	Variables	%
Age	18-21	80.5
	22-29	16.0
	30-39	3.0
	≥40	0.6
Sex	N/A	0.6
	Female	71.6
	Male	27.8
Classification	Freshman	15.4
	Sophomore	35.5
	Junior	32.5
	Senior	16.6
Area of Study	Anthropology	18.3
	Other Liberal Arts	25.4
	Science	3.6
	Health Professions	1.8
	Fine Arts	14.2
	Education	7.1
	Business	11.8
	Applied Arts	15.4
Taught evolution in high school?	Undecided	2.4
	No	35
	Yes, with creation	19
	Yes, without creation	45
	Can't remember	1

Statistics

The chi-square statistical test was used to assess any significant differences between males and females, and between students taught and not taught evolution in high school. Additionally, chi-square was used to test any potential interactions between survey statements. The chi-square tests evaluates the difference between the observed outcome and a predicted outcome. To obtain chi-square values for the interaction statements, SAS was used (SAS Institute Inc. 2002). For the purpose of this survey, it was anticipated for there to be no statistical difference based on sex, how a student was taught in high school, or on how a participant responded to certain statements.

Part III: Results

As displayed in Table 1, the students were evenly divided between lower and upper classmen (50.9% freshmen and sophomores, 49.1% juniors and seniors). Over 80% of students were between 18-21 years old and were majoring in anthropology or another liberal arts field. Females far outnumbered males within the class (72% female vs 28% male). Forty-five percent of participants reported being taught evolution in high school, 19% reported being taught both evolution and creationism, and 35% reported not being taught evolution at all. This could mean that 54% of students were improperly taught evolution at their high school.

Sex Differences

By using the chi-square test, statically significant differences ($p \leq 0.05$) were found between male and female responses in three of the survey statements (Table 2). The first of these statements is statement 15, “New traits within a population appear at random;”

Table 2. Student Responses

#	Category	Statement	% Response					
			1	2	3	4	5	6
1	SF	There is lots of evidence against evolution.	5	15	15	53	12	0
2	SF	Dinosaurs and humans lived at the same time during the past.	5	15	15	53	11	1
3	SF	Humans and chimpanzees evolved separately from an ape-like ancestor.	26	39	11	11	13	1
4	LS	I have a clear understanding of the meaning of scientific study. ^o	40	43	10	4	2	0
5	ET	The theory of evolution correctly explains the development of life.	37	36	15	7	5	0
6	LS	A scientific theory that explains a natural phenomenon can be defined as a "best guess".	11	30	25	17	17	0
7	PE	Small population size has little or no effect on the evolution of a species.	2	10	36	42	11	0
8	PE	If two light-skinned people moved to Hawaii and got very tan their children would be more tan they they (the parents) were originally.	1	12	28	51	7	0
9	PE	Variation among individuals within a species is important for evolution. ^o	63	33	1	1	2	0
10	PE	A species evolves because individuals want to.	2	10	29	53	7	0
11	ET	Humanity came to be through evolution, which was controlled by God. ^o	15	18	11	35	21	0
12	PE	A species evolves because individuals need to. ^o	54	28	7	5	5	1
13	PE	I have a clear understanding of the term "fitness" when it is used in a biological sense.	35	28	20	9	8	0
14	PE	Two of the most important factors that determine the direction of evolution are survival and reproduction.	65	28	2	2	2	1
15	PE	New traits within a population appear at random.*	10	23	40	23	4	1
16	PE	The environment determines which new traits will appear in a population.	37	49	7	2	4	2
17	PE	If two distinct populations within the same species begin to breed together this will influence the evolution of that species.	56	31	3	3	5	2
18	PE	All individuals in a population of ducks living on a pond have webbed feet. The pond completely dries up. Over time, the descendants of the ducks will evolve so that they do not have webbed feet.	35	39	13	5	7	1
19	PE	"Survival of the fittest" means basically that "only the strong survive".*	31	31	15	17	3	2
20	ET	You cannot prove evolution happened.	5	7	27	50	10	1
21	PE	Evolution cannot work because one mutation cannot cause a complex structure (e.g., the eye).	3	6	25	36	29	2
22	PE	Evolution is always an improvement. ^o	7	20	38	21	13	2
23	LS	A scientific theory is a set of hypotheses that have been tested repeatedly and have not been rejected.*	61	24	5	3	4	2
24	PE	If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than individuals in their parents' generation.	24	36	18	7	15	1

30.6% of females and 36.2% of males agree, 61.2% of females and 63.8% of males disagree, and 8.3% of females and 0% of males were undecided or left the question blank. Statement 19, “Survival of the fittest’ means basically that only the strong survive” also had significant response differences between males and females. Sixty-four

percent of females and 59.6% of males agree, 28.1% of females and 40.4% of males disagree, and 8.3% of females and 0% of males were undecided or did not respond to the statement. Lastly, statement 23, “A scientific theory is a set of hypotheses that have been tested repeatedly and have not been rejected” was found to have significant sex differences. Eighty-three percent of females and 91.5% of males agree, 8.3% of females and 8.5% of males disagree, and 9.1% of females and 0% of males were undecided or did not leave a response. In all three of these statements, it is evident that males were more decisive in their responses, and females were more likely to be undecided or unresponsive.

Differences Between Students Taught and Not Taught Evolution

Chi-square statistics were also used to evaluate statistical differences in the responses of students taught evolution in high school and those not taught evolution. Of the 24 statements, 5 were found to have statistical significance. Of the responses to statement 4 “I have a clear understanding of the meaning of scientific study,” 90.8% of students taught evolution and 75.9% of students not taught evolution agree, 7.9% of those taught evolution and 20.7% of those not taught evolution disagree, and 1.3% of students taught evolution and 3.4% of students not taught evolution were undecided or did not respond. For statement 9, “Variation among individuals within a species is important for evolution,” 100% of students taught evolution and 91.4% of those not taught agree, 0% of students taught evolution and 6.9% of students not taught evolution disagree, and 0% of students taught evolution and 1.7% of those not taught evolution were undecided. Of the responses to statement 11, “Humanity came to be through evolution, which was controlled by God,” 30.3% of students taught evolution and 36.2% of those not taught

evolution agree, 48.7% of students taught evolution and 41.4% of those not taught evolution disagree, and 21.1% of students taught evolution and 22.4% of those not taught evolution were undecided. Statement 12, “A species evolves because individuals need to” was also found to have statistical differences between responses. Seventy-five percent of students who were taught evolution and 89.7% of students not taught evolution agree, 17.1% of students who were taught evolution and 3.4% of students who were not taught disagree, and 7.9% of students who were taught evolution and 6.9% of those who were not were undecided or did not respond. Lastly, for statement 22, “Evolution is always an improvement,” 19.7% of students who were taught evolution and 36.2% of those not taught evolution agree, 71.1% of those who were taught evolution and 43.1% of those who were not disagree, and 9.2% of students who were taught and 20.7% who were not taught were undecided or left the question blank. Like the differences seen in males and females, those who were not taught evolution seemed to be less confident in their answers. Those that were taught evolution in high school were more confident in their answers, and were generally more likely to answer correctly.

In Table 2, the complete distribution of student responses to all 24 statements is presented. The most common misconceptions are highlighted yellow to help discern which concepts students seemed to have the least understanding. Table 3 displays the interaction between the statements. To maintain consistency with Dr. Cunningham and Dr. Wescott’s original study, the statements were divided into three categories: evolutionary theory and scientific facts, process of evolution, and language of science. Categorizing the statements proved to be useful in analyzing the data.

Table 3. Interaction Statements

Statement	Interaction statement	Agree with statement			Disagree with statement			Undecided about statement			
		%A	%D	%U	%A	%D	%U	%A	%D	%U	
Evolutionary theory and scientific facts	1	6*	51.4	31.4	17.1	41.6	46.9	11.5	25.0	30.0	45.0
		10*	17.1	77.1	5.7	8.0	89.3	2.7	30.0	45.0	30.0
		11*	42.9	25.7	31.4	28.3	55.8	15.9	35.0	30.0	35.0
		12	82.9	8.8	8.8	79.7	14.2	6.2	90.0	5.00	5.0
		20*	23.6	58.9	17.7	6.3	88.3	5.4	20.0	60.0	20.0
		21*	27.2	39.4	33.3	5.4	71.4	23.2	0.0	40.0	60.0
	5	6	40.2	42.6	17.2	46.0	43.2	10.8	40.0	30.0	30.0
		9	95.9	2.5	1.7	94.6	2.7	2.7	100	0	0
		10*	11.5	82.8	5.7	11.1	86.1	2.8	20.0	50.0	30.0
		11*	27.1	55.0	18.0	56.8	27.0	16.2	10.0	10.0	80.0
Process of evolution	12	84.4	9.0	6.6	73	18.9	8.1	80.0	20.0	0	
	9	16	88.0	1.9	3.8	75.0	0	0	100	0	0
		24*	62.0	25.7	13.3	50.0	0	50.0	0	33.3	66.7
	12	8	14.5	79.0	6.5	10.0	85.0	5.0	9.1	72.7	18.2
		11	35.5	44.2	20.3	20.0	60.0	20.0	18.2	45.5	36.4
Language of science	13	18*	77.0	19.3	3.7	75.0	15.0	10.0	45.5	18.2	36.4
		14	94.3	3.8	1.9	93.8	2.1	4.2	85.7	7.1	7.1
		16	89.4	1.9	2.9	85.4	0	4.2	76.9	7.7	7.7
		19	63.7	34.3	2.0	68.8	29.2	2.1	50.0	35.7	14.3
	4	6*	42.9	43.6	13.6	37.5	41.7	20.8	25.0	0	75.0
	23	88.3	8.0	3.7	82.6	13.0	4.4	75.0	0	25.0	

* $p < 0.05$ (statistically significant interaction)

Evolutionary Theory and Scientific Facts

Statements 5, 11, and 20 all address opinions surrounding the validity of evolutionary theory. These statements were designed to gauge the participant's personal opinions regarding the credibility of the theory of evolution. Figure 1 displays the responses to each of these statements. The responses to statement 5 show that most participants (72%) agree that "The theory of evolution correctly explains the development of life" (Table 2). Participants were more varied in their responses to statement 11 ("Humanity came to be through evolution, which was controlled by God"). However, the majority (46%) disagree with this statement. Statements 1-3 address scientific facts (Table 2). As seen in Table 2, most participants (67%) disagree with statement 1 ("There is lots of evidence against evolution") and 68% disagree with statement 2 ("Dinosaurs and humans lived at the same time in the past"). The majority (65%) of participants agree with statement 3, that "humans and chimpanzees evolved separately from an ape-like ancestor" (Table 2).

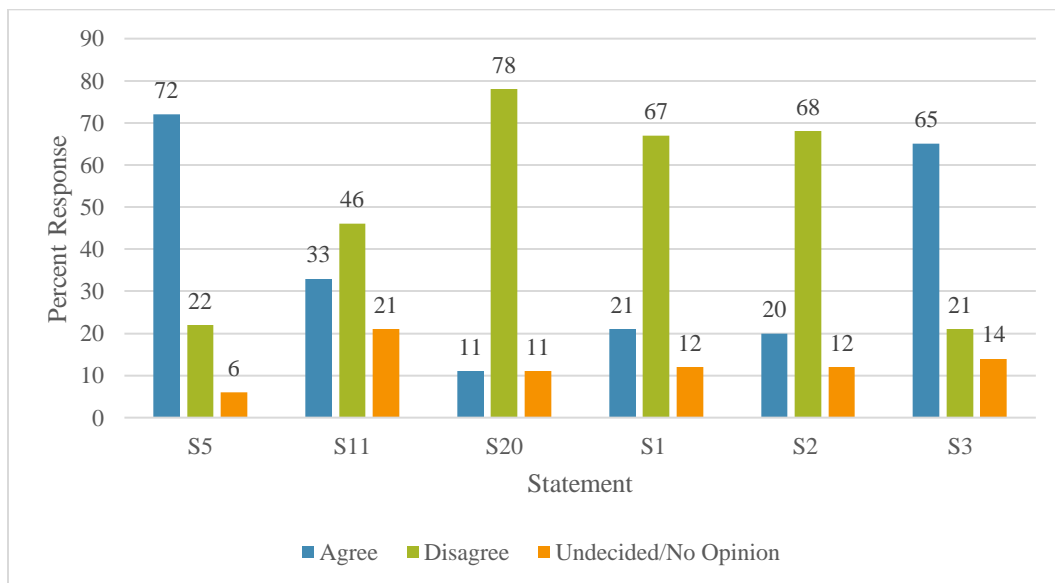


Figure 1 Percent of student response to statements regarding the theory of evolution and scientific facts.

To further explore student responses to statement 1 “There is a lot of evidence against evolution”, the interactions between this statement and statements 6, 10, 11, 12, 20, and 21 were analyzed. Over half of the students who agree that there is a lot of evidence against evolution also agree that a scientific theory is defined as a “best guess” (statement 6). Nearly half of those who disagree that there is a lot of evidence against evolution also disagree that a scientific theory is a best guess (Table 3). The majority of students (77%) who agree that lots of evidence against evolution exists disagree that species evolve because they want to (statement 10). Even more students (89%) who agree with statement 1 disagree with statement 10. Most of the students who agree that there is a lot of evidence against evolution also agree that evolution is controlled by God, while most of the students who disagree with statement 1 also disagree with statement. The responses to statement 12 indicate that the misconception that individuals evolve because they “need” to is widespread among the class. Eighty percent of those who disagree with statement 1 agree that evolution is driven by need, while 83% of those who agree with statement 1 agree with statement 12 and 90% of those who were undecided about statement 1 agree with statement 12. It seems that, regardless of how students responded to statement 1, most students disagree with statement 20, “You cannot prove that evolution happened.” However, nearly a quarter of students who agree that evidence against evolution exists also agree that evolution is not provable. Students were more likely to agree with statement 21 (Evolution cannot work because one mutation cannot cause a complex structure) if they agreed that there is evidence disproving evolution. However, 71% of students that disagree with statement 1 also agree with statement 21 (Table 3).

Most of the interactions between the above statements were found to be statistically significant. As labeled in table 3, interactions between statement 1 and statements 6, 10, 11, 20, and 21 were all found to be significant after the application of a chi-square test. Statement 12, “A species evolves because individuals need to” was agreed upon by the majority of students, regardless of how they responded to statement 1. This misconception that evolution is driven by individuals’ “need” is extremely common among the class, as was the case in the 2009 study (Cunningham and Wescott 2009).

The interactions between statement 5, “The theory of evolution correctly explains the development of life” and other statements were also evaluated. This statement, as stated in the original survey, is a direct way of determining how valid the participants think the theory of evolution is (Cunningham and Wescott 2009). The interactions between this statement and statements 6, 9, 10, 11, and 12 are displayed in table 3. Interestingly, students that agree with statement 5 seem to be split between their responses to statement 6, “A scientific theory that explains a natural phenomenon can be defined as a ‘best guess’” (40% agree, 43% disagree, 17% undecided). Likewise, students that disagree or were undecided on statement 5 were also split on statement 6 (Table 3). Regardless of how valid a participant thinks evolution is, it seems that the word “theory” is a consistent source of confusion for students. Most students agree with statement 9, that “Variation among individuals within a species is important for evolution,” regardless if they accept or deny evolution as being true (Table 3). When looking at the responses to statement 10 “A species evolves because individuals want to”, the responses seem much more divided. Eighty-three percent of individuals who agree that the theory of evolution correctly explains the origin of life disagree that a species evolves because the individuals

need to (Table 3). Additionally, most students who disagree with or were undecided on statement 5 also disagree that evolution is driven by individual want. Those who agree with statement 5 were also more likely to agree that species evolve because individuals need to (statement 12). Seventy-three percent of students who disagree with statement 5 agree with statement 12, and 80% of students who were undecided on statement 5 agree with statement 12.

Students seemed to vary among their responses to statement 11, “Humanity came to be through evolution, which was controlled by God.” Fifty-five percent of students who agree with statement 5 disagree with statement 11, while 27% agree and 18% are undecided. Fifty-seven of those that disagree with statement 5 agree with statement 11, 27% disagree and 16% were undecided. Lastly, those who were undecided on statement 5 were much more likely to be undecided on statement 11 (80%). Theistic evolution seems to be more popular among students who do not accept the theory of evolution, and less popular among the students who do accept evolution to be factual (Table 3).

When applying chi-square statistics to these interactions, it was found that the interactions between statement 5 and statements 10 and 11 were statistically significant. There are many similar patterns of interactions between statement 1 and statement 5, including misconceptions regarding the meaning of a scientific theory, and the idea that evolution is driven by need.

Process of Evolution

The majority of statements in the survey explore the process of evolution (Table 2). The responses to statements 7-10 show that most of the students understand the importance that variation and population size has on the evolution of a population.

Additionally, these results show that most of the students did not hold the misconception of soft inheritance to explain skin color, and that most students understand that species do not evolve because they “want” to (Gregory 2009; Table 2). Most participants (92%) agree with statement 14, and seem to understand that survival and reproduction are key elements in the process of evolution. Most of the students (87%) agree with statement 17, that interbreeding between populations will affect the direction of evolution, and most disagree with the statement that a mutation cannot produce a complex structure (60% disagree with statement 21). Lastly, most students (59%) disagree with statement 22, that evolution is always an improvement.

Despite these encouraging results, students did demonstrate many common misconceptions in their results. The majority of participants (62%) fail to understand that new traits appear at random within a population (statement 15). While most students correctly disagree that individuals evolve because a species wants to, a high percentage of students (82%) agree with the statement that species evolve because individuals need to (statement 12). These responses indicate a high level of teleological explanations for evolution: the misconception that evolution is driven by purpose, need, or want, and has an end goal (Gregory 2009). Another common misconception within the class is the definition of the phrase “survival of the fittest.” Sixty-two percent of students think that this phrase means that “only the strong survive” (statement 19). This phrase is misleading; Darwin didn’t coin this phrase himself and didn’t even start using it until his 5th edition of *On the Origin of Species* (Gregory 2009). Fitness, in a Darwinian sense, has nothing to do with physical strength. It has everything to do with how well-suited an

individual is to their environment, and how well they can survive and reproduce within their environment, relative to other individuals.

The relationships between students' responses to statement 9 "Variation among individuals within a species is important for evolution" and statements 16 and 24 were evaluated. Of the individuals who agree that variation is important for evolution, 88% also agree that the environment determines which new traits will appear in a population (statement 16). Additionally, of those who disagree with statement 9, 75% agree with statement 16 and 100% of those who are undecided on statement 9 agree with statement 16. Statement 24 "If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than individuals in their parents' generation" is designed to test students' knowledge on population variation, origin of traits, and survival of traits via natural selection (Cunningham and Wescott 2009). Of the students who agree with statement 9, the majority (62%) agree with statement 24. Students who disagree with statement 9 were evenly divided in their responses to statement 24, with 50% agreeing and 50% remaining undecided. The majority (67%) of students who were undecided on statement 9 were also undecided on statement 24. These results, like the results found in the original study, reinforce the idea that while students understand that variation is important, they do not understand why this is or where variation comes from (Cunningham and Wescott 2009). The relationships between statement 9 and statement 24 were found to be statistically significant.

Interactions of statement 12 "A species evolves because individuals need to" were also analyzed. Of the students who agree with statement, only 15% agree with statement 8, which implies that acquired traits are heritable (Table 3). This "partial acceptance" of

Lamarckian inheritance was also discovered in the original study (Cunningham and Wescott 2009). Of the students who agree with statement 12, 36% also agree with statement 11, “Evolution is controlled by God”. Of the students who disagree with statement 12, only 20% agree with statement 11. While the pattern is more pronounced than in the original study, it would seem that those who think evolution is driven by need are more likely to believe that the process of evolution is commanded by God. Students seem to believe that it is the environment that controls the need to evolve. Of the participants who agree with statement 12, 77% also agree with statement 18, “All individuals in a population of ducks living on a pond have webbed feet. The pond completely dries up. Over time, the descendants of the ducks will evolve so that they do not have webbed feet.” Responses to statement 16 also confirm this; 86% agree that the environment determines which traits will arise in a population (Table 2). The interaction between statements 12 and 18 was found to be statistically significant after the application of a chi-square test.

Most students correctly agree with statement 14 “Two of the most important factors that determine the direction of evolution are survival and reproduction,” regardless of how they responded to statement 13, “I have a clear understanding of the term “‘fitness’ when used in a biological sense.” However, regardless if a student agreed, disagreed, or were undecided on statement 13, students overwhelmingly agree that survival of the fittest means that “only the strongest survive” (statement 19; Table 3). As stated in the 2009 study, confidence does not correlate with correctness (Cunningham and Wescott 2009). Lastly, students also mostly agree with statement 16 “The environment determines which new traits will appear in a population”, no matter how they responded

to statement 13. There were no statistically significant relationships between statement 13 and statements 14, 16, or 19.

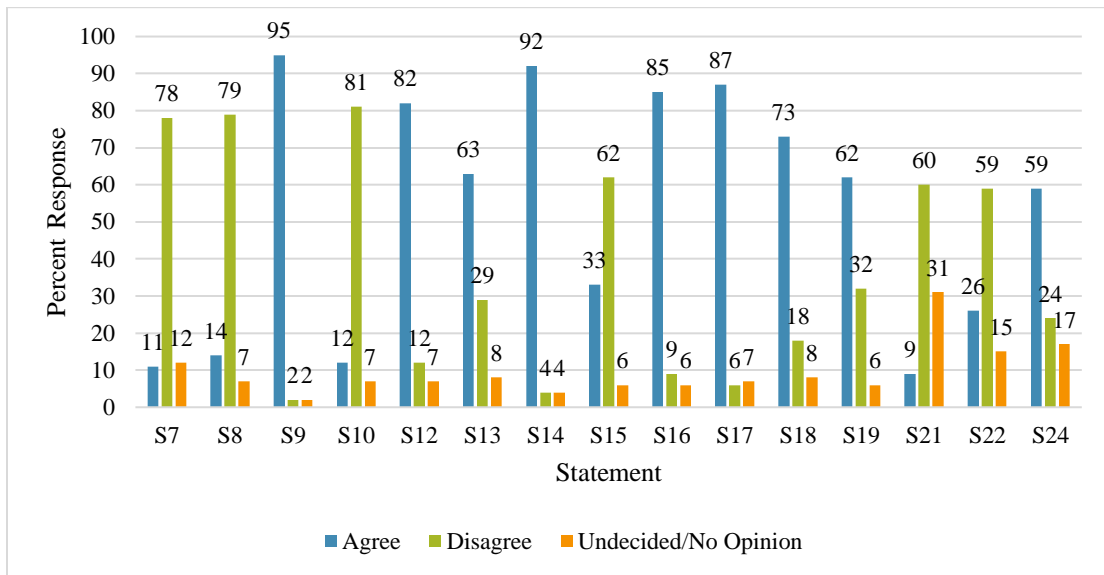


Figure 2 Percent of student response to statements regarding the process of evolution.

Language of Science

One of the most common misconceptions regarding evolution is the definition of the word “theory.” Theory has very different meanings depending on the context of how it’s used, as the vernacular definition of theory is not the same as a scientific theory. A scientific theory is essentially a fact, but because of the self-correcting and ever-improving nature of science, it is important to consider the possibility of new evidence arising (Bishop and Anderson 1990; Gregory 2007). Several statements in the survey were designed to gage how well students understood the different definitions of “theory.” Students were evenly split between agreeing (41.4%) and disagreeing (42%) with statement 6, that “A scientific theory that explains a natural phenomenon can be defined as a ‘best guess’.” This was re-worded in statement 23, “A scientific theory is a set of hypotheses that have been tested repeatedly and have not been rejected.” It was found that many more participants (85.2%) agree with this statement. When looking at

responses to statement 4, “I have a clear understanding of the meaning of scientific study,” it is apparent that most of the participants (82.8%) agree that they do.

Of the students who agree (83%) with statement 4, 43% agreed and 44% disagreed with statement 6, that “A scientific theory that explains a natural phenomenon can be defined as a "best guess." As demonstrated in previous interactions, students may not understand science concepts as well as they report understanding. As observed in the original study, students were much more likely to agree with statement 23, no matter how they responded to statement 4. Eighty-eight percent of those who agreed with statement 4 agree with statement 23, 83% of students who disagreed with statement 4 agree with statement 23, and 75% of those who were undecided on statement 4 agree with statement 23. This implies that even if a student doesn’t understand scientific concepts, they can recognize scientifically correct statements.

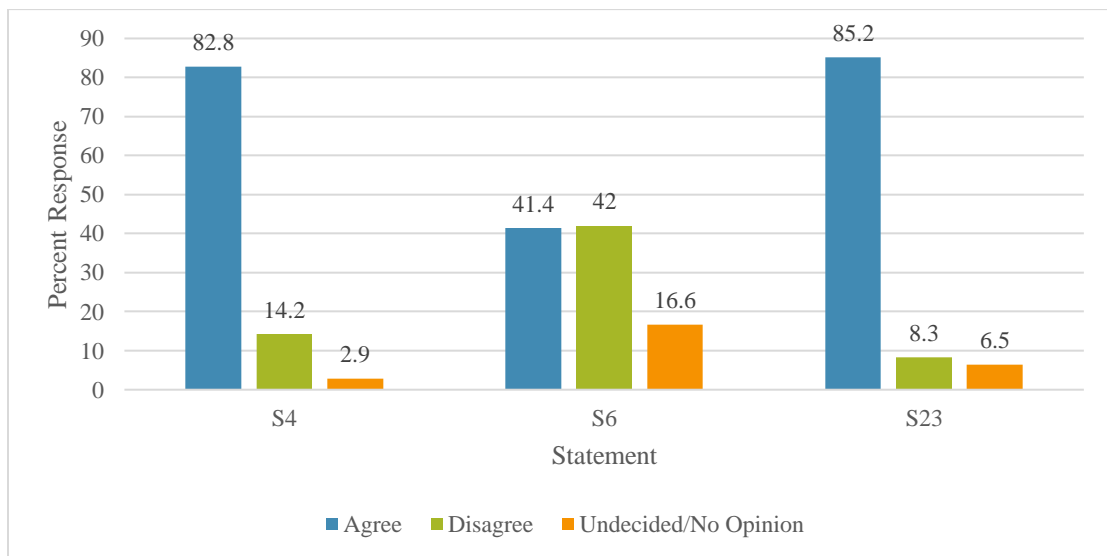


Figure 3 Percent of student response to statements regarding the language of science

Geographic Data

To understand how geography plays a role in science education, all survey participants were asked to provide what high school they attended, and if and how they were taught evolution there. The reported high schools located in Texas (n=128) were then mapped using ArcGIS Pro. While no discernable trends are visible on the map, it is worth noting how varied the participants from major urban areas were in their responses (i.e. Dallas-Fort Worth, Houston, Austin, and San Antonio). A total of 15 participants attended high school in the Dallas-Fort Worth area. Eight of these students reported being taught evolution, and six reported not being taught evolution, and one reported being taught both in high school.

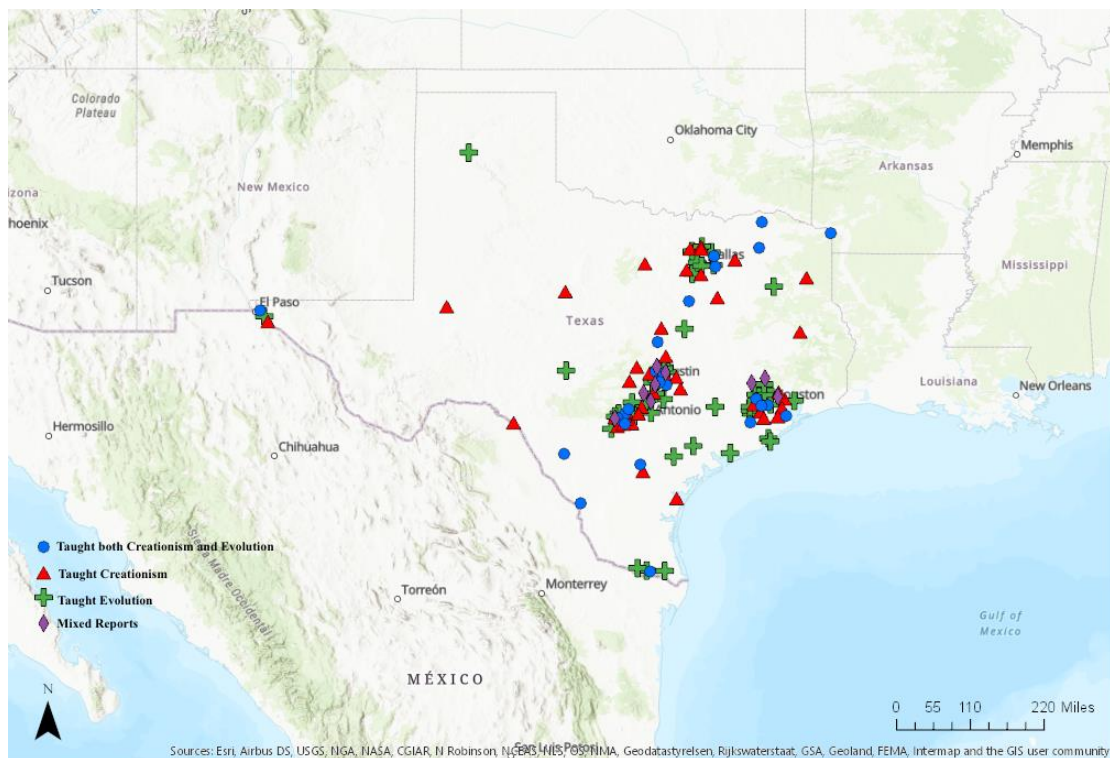


Figure 4 Geographic distribution of Texas high schools attended by participants.

Of the 25 students from Houston, 12 reported being taught evolution, six reported being taught creationism, four reported being taught both, and there were three instances of mixed reports- students who attended the same school but reported learning different things in their classrooms. In San Antonio, five of the 17 students reported being taught evolution, seven were not taught evolution, four were taught both, and there were three cases of mixed reports. Lastly, in Austin, arguable the most progressive of the cities, six of the 16 students reported being taught evolution in high school. Three reported learning creationism, four reported learning both, and there were three mixed reports.

Part IV: Discussion

Comparison of Trends: A Decade Later

In the final analysis of this study, the percent response to each statement from both the 2009 paper and the current date were compared to see how the results have changed over the past ten years. We found that overall, the general trends have not changed much. When comparing the results from the statements focused on evolutionary theory and scientific facts, there are some slight changes. Statements 5, 11, and 20 had the most dramatic changes in percent response. For statement 5 “The theory of evolution correctly explains the development of life” number of students who agree jumped from 55% to 72%, and the number of students undecided on this statement decreased by 9 percent points (Figure 5). This is a particularly encouraging result, as it implies that over the last decade, more young adults accept the validity of the biological theory of evolution. The percent of students who agree with statement 11 “Humanity came to be through evolution, which was controlled by God” experienced a 4-percentile point drop, while the percent of those who disagree with theistic evolution experienced a 10% increase. Statement 20 “You cannot prove that evolution happened” experienced a 21%

jump in the percentage of students who disagree. All of these results are encouraging, and show that understanding of evolutionary theory has shown some improvement over the last decade. In all the statements regarding evolutionary theory and scientific facts, students were more decisive in 2019 than they were in 2009, save for statement 20, which didn't experience any change in the percent of those undecided.

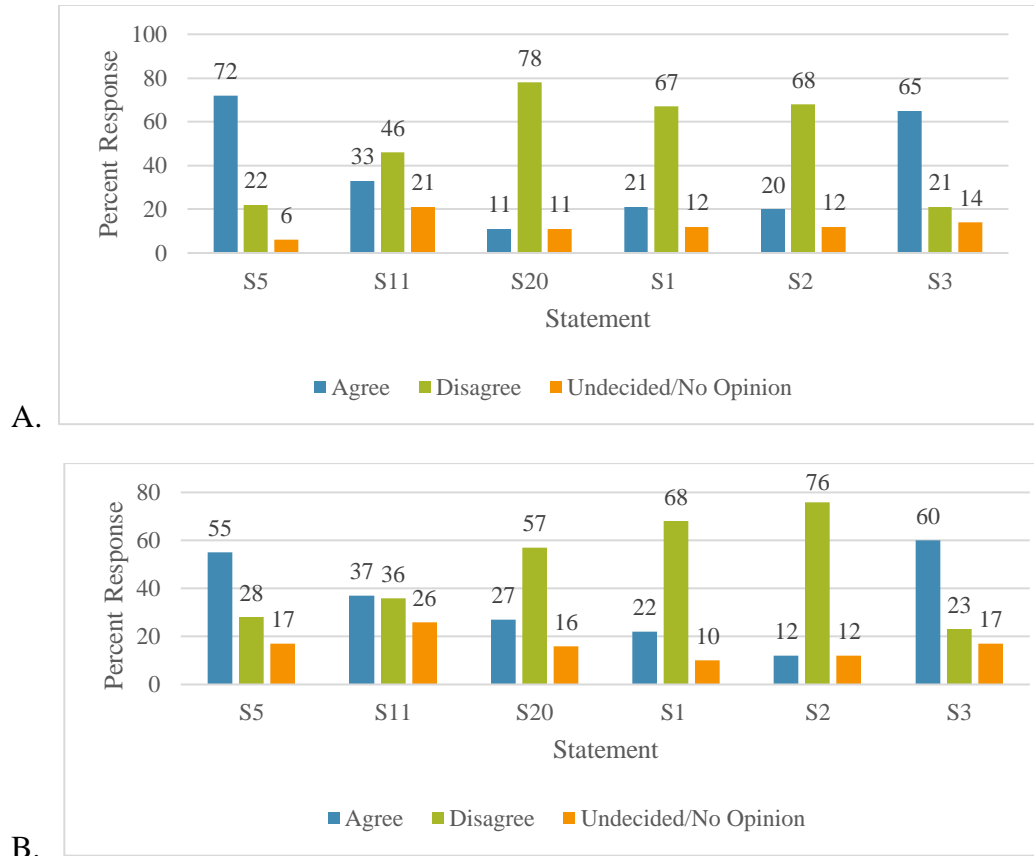


Figure 5 Trend comparison between the 2009 and 2019 studies regarding statements that cover evolutionary theory and scientific facts. Graph A are the results of the 2019 study are pictured on top, and Graph B are the results from 2009. See Table 2 for full statements.

Comparisons of the responses to statements focused on the process of evolution also demonstrate similar trends of minimal change. The statements that had the most noticeable change were 9, 12, 13, and 15. The percent of students who agree with statement 9 “Variation among individuals within a species is important for evolution”

went from 85% in 2009 and 95% in 2019 (Figure 6). Statement 12 (A species evolves because individuals need to) also experienced a considerable change. Only 66% of students agreed with statement 12 in 2009, while 82% of students agreed in 2019, implying that need-based explanations for evolution have become more common. Fifty-three percent of students agreed that they have a clear understanding of the term “fitness” in 2009, while 63% agreed in 2019. However, more students in 2019 disagree with statement 15, “New traits within a population appear at random.”

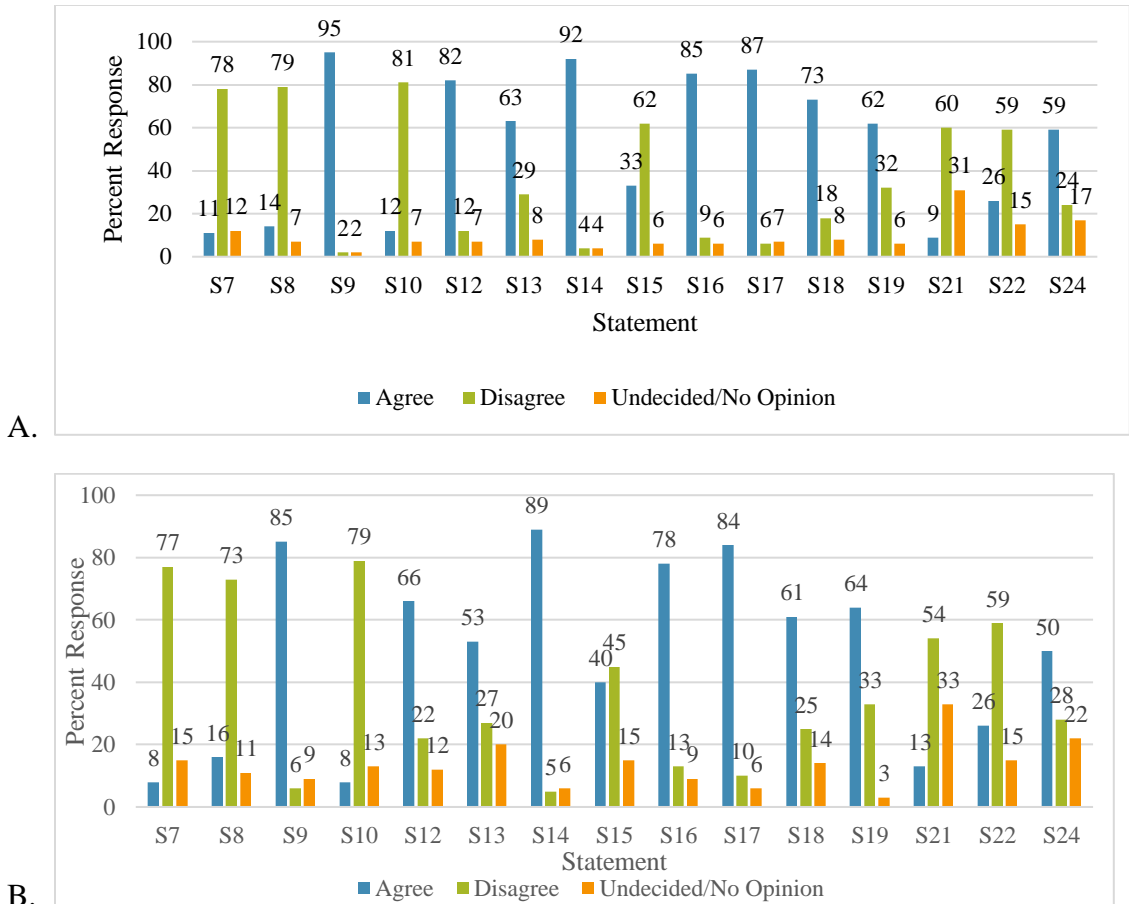


Figure 6 Trend comparison between the 2009 and 2019 studies regarding statements that cover the process of evolution. Graph A are the results of the 2019 study are pictured on top, and Graph B are the results from 2009. See Table 2 for full statements.

These results are mostly encouraging- while the participants of the 2019 study demonstrated a fair number of misconceptions regarding evolution, overall understanding has improved in the last decade.

Finally, we compared the results of the statements focused on the language of science. While slight changes were present, there was not significant difference in how students responded to these statements. These results are encouraging. While there wasn't much significant change, there were noticeable improvements in the level of understanding for many statements.

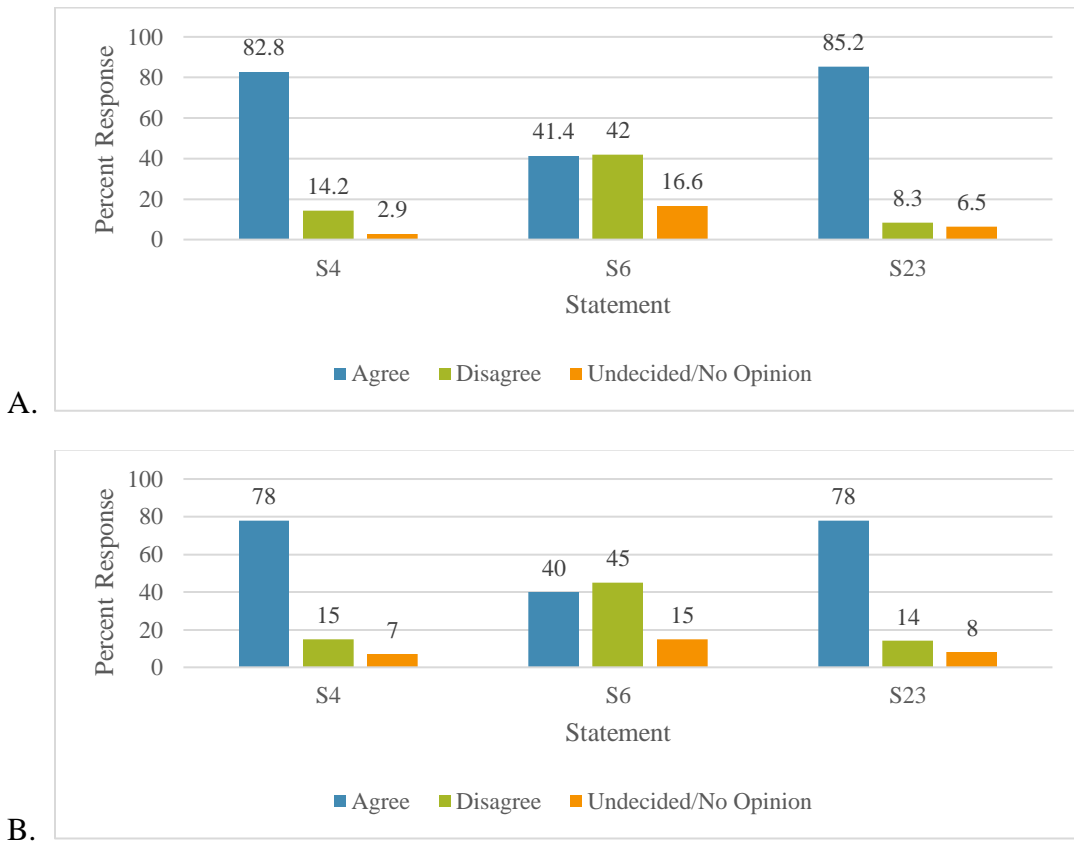


Figure 7 Trend comparison between the 2009 and 2019 studies regarding statements that cover the language of science. Graph A are the results of the 2019 study are pictured on top, and Graph B are the results from 2009. See Table 2 for full statements.

Additionally, in almost all statements, there was a decrease in the percentage of students who were undecided. It was found that there was improvement in responses in almost every case, even if minimal. This could be a result of evolution becoming more commonplace in science classrooms, and this trend of increasing understanding could possibly become even more evident in the coming years.

Interestingly, less students reported being taught solely evolution in high school (51% in 2009 vs 45% in 2019) (Cunningham and Wescott 2009). Despite this, students seem to have a slightly better understanding than the participants of the original study. This could be due to students learning evolutionary concepts on their own, perhaps by finding educational content on the internet. Likewise, less students turn to theistic explanations for life in 2019 (Figure 5, statement 11). It is possible that reduced belief in religious ideals has led to more students accepting evolution, even if they still have misconceptions.

Geographic Trends

When looking at Figure 4, it is difficult to decipher any notable geographic trends, apart from the three schools in rural north central Texas that were reported teaching creationism. Other than those three schools, there does not seem to be a difference between how urban and rural schools teach evolution. In the greater urban areas, such as Dallas-Fort Worth, Houston, and Austin, there are many cases of high schools teaching evolution, but also many were reported teaching creationism. The common practice of teaching creationism in public schools is particularly surprising to see in Austin, a city that is reputedly liberal and progressive. In nine instances, participants who attended the same high school at the same time reported learning different explanations for the

evolution of diversity of life. These data indicate that where a student learns evolutionary concepts is not as important as who is teaching them. It seems that teachers, even those who teach at the same school, may teach their students different concepts in their science classrooms. While teaching creationism in public schools is unconstitutional, it does not seem that a teacher's individual approach to teaching evolution is closely monitored by any district.

There were three participants who did not attend high school in Texas. One attended high school in Germany, one in Iowa, and one in South Carolina. Interestingly, all three of these individuals reported learning creationism in their high school science classes. Teaching creationism is relatively common throughout the United States, so it was not surprising to see the Iowa and South Carolina students learning creationism. However, the individual from Germany who reported not learning evolution implies that this could be a global issue, and would be an interesting start for further research.

Additional data from Texas State University

In addition to the data collected in this study, there are pre-existing data that indicate low levels of scientific literacy and evolution understanding among students. Dr. James Ott, an associate biology professor at TXST, has been keeping track of student performance in his Evolution course (Table 4). Over the past 9 semesters, it was found that final grade distributions were shockingly poor. Of the 1051 students included in this data set, only 66 (6.2%) made an A in the course. Nearly 38% of students fail to pass the course. These numbers could simply be a reflection Dr. Ott's teaching style, but it should also be noted that it is disclosed in the Evolution syllabus that the course is challenging and requires dedication, focus, and many hours of studying. Evolution is an advanced

biology elective at Texas State, which requires several prerequisite courses that also cover evolutionary concepts. It should not be surprising that Dr. Ott holds his students to a high standard and expects them to start the course already familiar with the theory of evolution. Considering this, it is possible that students at Texas State University either have a very difficult time learning evolutionary concepts, or they are uninterested in putting in the effort to learn. Either way, these numbers are disappointing for students who are in a higher education environment and have previously completed introductory biology courses.

Table 4. Final grade distributions for Dr. James Ott’s Evolution course

	Fall 2010	Spring 2011	Fall 2011	Spring 2012	Spring 2013	Fall 2014	Spring 2015	Spring 2016	Spring 2017	SUM	%
A	5	6	5	8	8	7	14	6	7	66	6.2
B	22	22	26	17	31	13	21	18	25	195	18.4
C	37	50	59	48	38	43	35	35	44	389	36.6
D	26	19	28	29	9	54	38	33	37	273	25.7
F	23	7	19	7	3	31	16	14	18	128	12.1

Teaching strategies to overcome misconceptions

While it is possible to eliminate deeply-held misconceptions at the college level, traditional lectures may not be the best format to do so (Cunningham and Wescott 2009). The most important step for an educator to take in helping eliminate misconceptions is to understand the specific misconceptions that are most prevalent within the class. Using an assessment tool such as a survey is a good way to gauge students’ understanding. Helping students make conceptual changes in their minds involves more than just presenting them with correct information; students need to explicitly identify misconceptions and solve problems based on their misconceptions (Cunningham and Wescott 2009). Additionally, it is important for the instructor to explicitly state definitions of commonly confusing

terminology, such as the words “theory” and “fitness.” These teaching methods can also be applied to high school education. However, it is important for teachers to understand the religious and political background of their community. Additionally, introducing evolution to students as strictly science and not a philosophical belief is one way to eliminate the amount of discourse within the classroom.

Flaws in the study and further questions

Unfortunately, the study was not completely consistent with Cunningham and Wescott’s original survey. The 2009 survey was administered on the first day of class, while administration of the 2019 survey wasn’t possible until the third day of classes, due to scheduling. However, this delay is not thought to have had a significant impact on the survey results, as the lecture hadn’t delved deeply into evolutionary theory. Additionally, some surveys were unable to be used in the data set. The qualifications to be used in the were 1) a completed background section and 2) more than 50% of the survey questions answered. One participant did not complete any of the background portion, one only answered the first 10 questions, and one checked off multiple boxes for many statements, making their responses invalid.

In an ideal setting, the survey would be re-administered to the same group of students to evaluate how well the Biological Anthropology course helped eliminate the student’s misconceptions about evolution. However, due to time constraints, this was not possible. Regardless, there are still many directions in which further research can go. Focusing on evolution education at the high school level, rather than the university level, may be the best route to eliminating misconceptions. Additionally, some of the most important implications found in this study were in the geographic analysis. These results

showed that teaching evolution varies more between individual teachers than it does between schools, and that lack of quality evolution education is not only a national issue, but potentially a global one. Extending this research by interviewing teachers would be useful. Understanding why an instructor might shy away from teaching evolution, whether it be due to personal convictions or from fear of parental backlash, is a good next step into uncovering why this is still an ongoing issue, and to what extent. It is possible that there were inconsistencies between what a student was actually taught in high school, and what they reported learning. Comparing teacher reports, student reports, high school syllabi, and the state science standards would all help to further explain the results of this study. Additionally, extending surveys like this into foreign countries would also give insight to scientific literacy issues abroad. Getting an understanding of how students perceive evolution is the first step into helping them grasp evolutionary and other biological concepts.

Part V: Conclusion

The results of this survey are nearly identical to those found in the past (Almquist and Cronin 1988; Cunningham and Wescott 2009). High school evolution education is still lacking, and roughly half of students may not receive adequate information regarding evolutionary theory. While students need better evolution education, it does appear that the level of understanding students have is improving over time. To further improve students' knowledge, educators at both the high school and college levels must use proper tools and teaching practices to best help their students overcome misconceptions. By doing so, student's perceptions of science may continue to progress.

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