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Identifying misconceptions about evolution relative to science curriculum exposure at the secondary level

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This study took place at a moderately-sized school located in the Midwest. Students respond with their agreeability to a modified BEL Survey, a 22 question survey containing evolution-related misconceptions. This survey was distributed as a Google Form and was given before instruction using SEPUP biology's evolution unit as well as after. The data was analyzed using quantitative methods to measure the significance of conceptual change on a Likert scale. This study aims to find if there was a difference in students' evolution-related misconceptions after exposure to SEPUP biology curriculum.

For standard HS-LS4-1 and No Standard, students showed a statistically significant improvement in addressing the underlying misconceptions, however the effect sizes were small, 0.25 and 0.28 respectively. The SEPUP curriculum does a good job at addressing common misconceptions students have about biological evolution. Further data analysis into the standards that would address the misconceptions identified in the BEL Survey found that the categories No Standard and HS-LS1-1 had significant differences between pre and post-test scores.

Identifying Misconceptions About Evolution Relative to Science Curriculum Exposure at the Secondary Level

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Acknowledgments

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Chapter 1 - Introduction and Framework

Evolutionary theory is the backbone of the biological sciences. Theodosius Dobzhansky famously wrote, “Nothing in biology makes sense except in the light of evolution” (Dobzhansky, 1973, p.125). This idea is supported today by the place evolution related ideas hold in the Next Generation Science Standards (NGSS). The importance of evolution in the NGSS is that it requires schools to teach evolutionary theory to all students in the science classroom. Yet teaching about biological evolution presents significant challenges for students ranging from conflicts with students’ personal beliefs to their inability to relate evolutionary theory to their day-to-day lives (Heddy & Sinatra, 2013).

The NGSS website states their standards allow students to develop understanding of content along with developing skills such as communication, collaboration, and problem solving that will serve them throughout their lives (Lead States, 2013a). As students master these skills, they add to their scientific literacy, which is defined as the knowledge and understanding of scientific concepts as applied to decision making, participation in civic and cultural affairs, and economic productivity (Allison and Goldston, 2018, p. 280). However, scientific literacy in the United States is low with the proportion of adults in 2008 in the United States who were scientifically literate at 28% (Miller, 2016). This statistic brings into question whether students' misconceptions towards evolutionary theory play a role in their ability to apply scientific ways of thinking later in life. One of the aims of NGSS is to build students' understanding of evolutionary theory as one of the important science principles. As such, it is imperative to address the misconceptions students hold about evolutionary concepts so they can become scientifically literate members of society.

United States citizens have the power to elect representatives who reflect their interests when they are developing science standards by state. Therefore, the comprehension of evolution by the American public directly affects how science is taught in the United States as it influences their ability to vote for representatives who make rational decisions regarding science standards (Watts et al., 2016, p.60). This power highlights the importance of knowing where Americans stand when it comes to understanding and teaching evolution, as it has an important impact on the science standards, textbooks, and curriculum utilized.

In the state of Iowa, many school districts have adopted NGSS curriculum. These are developed through an interdisciplinary collaboration between international experts, stakeholders and the public and managed by the National Research Council, the National Science Teachers Association and the American Association for the Advancement of Science. The Iowa Department of Education used science educator review teams to determine the state level NGSS. This should translate into students graduating from Iowa high schools with a solid understanding of evolution and progress toward science literacy. In turn, this will assist students in their ability to make informed decisions in regards to science standards at the polls. To ensure this happens, their misconceptions on evolutionary science concepts need to be addressed in their instruction.

Previous misconceptions play a significant role in how high school students respond to the teaching of evolution, ranging anywhere from a lack of scientific understanding to their religious background. Many biology curricula are aligned to the NGSS, which has evolution as one of its disciplinary core ideas, insinuating its importance. But are all evolution-based curriculum units equal in quality in terms of their teaching of evolution-related concepts? Do all evolution-based curriculum units lead to equal changes in student thinking and understanding of evolution-related ideas? I am interested in how student understanding of evolution changes through instruction about evolution, or if these preconceptions are so ingrained they will not change.

The problem addressed in this study is to identify the misconceptions high school students hold about evolution based on the Biology curriculum used. Hanna (2011) identifies a disparity between how evolution is taught by teachers in Iowa high schools, which in turn leads to confusion and gaps in student knowledge. He went on to describe teacher factors contributing to gaps in student knowledge. These include "the amount of prior coursework in evolution, level of education/advanced degree, and membership to professional science-related organizations" (Hanna, 2011, p.128). Meir et al. (2007) described the importance of educators identifying sources of student biological evolution misconceptions and developing strategies to reduce or eliminate misconceptions. A teacher's failure to identify student misconceptions and take them into consideration when developing and implementing a curriculum is a major oversight when they are attempting to set up students for success in a technological advanced world (Meir et al., 2007, p.17). There is currently a gap in the literature regarding the degree to which specific biology curricula address common evolution-related misconceptions. Given this information, this study seeks to address the following research question. The research question is as follows:

1. How does exposure to the SEPUP biology curriculum affect the misconceptions about evolutionary theory held by 10th grade students?

Chapter 2 -Literature Review

The focus of this study is to investigate the impact of the SEPUP biology curriculum on the misconceptions held by 10th grade students. There is ample research about what misconceptions students hold about evolution, but noticeably less about how effective specific biology curricula are at identifying and addressing said misconceptions. I chose this research project because I was curious about the effectiveness of the science curriculum I used at providing lessons that would address common misconceptions. Comprehension of evolutionary theory is of great significance when it comes to building scientific literacy and educated citizens.

To better understand this study, one must understand what the NGSS consists of and how evolution is reflected in those standards. Additionally, a history of teaching evolution in the classroom and what impact that has had on how instructors teach evolution is important. Finally, misconceptions should be defined, and the biology curriculum that I used (SEPUP) should be analyzed to better understand the evolution concepts presented in that curriculum.

The Controversy Related to Teaching Evolution in the Science Classroom

The single most controversial educational issue of our time is possibly teaching of evolution in the high school classroom. In a survey, 83% of Americans agreed evolution should be taught in public schools (DYG, 2006). Despite that overwhelming agreement, there are powers throughout all levels of government working to stop the teaching of evolution in the classroom (Hall & Woika, 2018). Court cases such as Rodney LeVake v. Independent School District and Kitzmiller v. Dover Area School District demonstrate how significant this issue is

(Kitzmiller v. Dover Area School Dist., 2005). The Rodney LeVake case saw a teacher fighting for the ability to teach criticism of evolution in the classroom. The high courts declined to hear the case, as it was up to the district which standards were taught (Walsh, 2002). The case of Kitzmiller was the first challenge brought to a United States federal court over the teaching of intelligent design. The courts found that intelligent design would fall under religion, not the sciences, and therefore should not be taught in the science classroom (Kitzmiller v. Dover Area School Dist., 2005). The causes of non-acceptance of evolution stem from inadequate understanding of the evidence for modern evolutionary theory and/or the nature of science and how these interact with religion, politics and society (Allmon, 2011, p.648).

The most prevalent argument against teaching evolution in our schools comes from the perceived conflict between evolution and religion. Students often believe the two are incompatibile and completely separate. This idea is often due to the literal interpretation of the story of creation in the bible (Leveque & Guillaume, 2010). This conflict disrupts potential learning, which in turn sends students to college with a low level of understanding of evolution (Chinsamy and Plagányi, 2008). It has been well documented that educators must convey science and theology are separate and not dependent on each other. The combination of the conflict and the lack of understanding of evolution facilitates misconceptions inhibiting students' ability to comprehend pivotal concepts in higher level courses and beyond.

What are Misconceptions

A misconception is defined as “a perception of phenomena occurring in the real world which is not consistent with the scientific explanation of the phenomena”(Modell et al. 2005, p.20). Students enter the science classroom with preconceived understandings of the content being covered. Misconceptions range from a misunderstanding of vocabulary to complete theory rejection. These misconceptions are usually strongly held and complex, which makes them barriers to students' understanding of evolution (Meir et al., 2007). It is the job of the teacher to address the student misconceptions in order to build understanding and scientific literacy.

Misconceptions also vary depending on the student's cognitive development. Piaget (1954) viewed intellectual growth as a process of adaptation to the world through assimilation and accommodation. His concept of assimilation, or the process of taking in and understanding information, helped us understand that new information can be learned more easily when it's related to something the student already knows (Longfield, 2009). When students are presented with a new situation, they go through a period of disequilibrium where they cannot fit the new information into their prior schema. According to Piaget, in order for learning to take place prior to disequilibrium, the learner must go through a stage of accommodation, or learning where they must revise what they already know, to learn a new idea (Longfield, 2009).

Teachers being knowledgeable about student misconceptions is crucial to student learning. Students come into the classroom with their own pre-existing knowledge, skills, beliefs, and attitudes that can influence their ability to learn and retain knowledge. For this reason, it is important to recognize what students know and can do before instruction begins in order to address any weaknesses while highlighting their strengths. If a teacher identifies their class as possessing misconceptions, they may cover it in their instruction, provide a specific lesson covering it, or provide the class with materials allowing them to investigate the misconception on their own (Assessing Prior Knowledge, 2022). This idea recognizes learning is as much about unlearning old ideas as it is about learning new ones. In a study by Sadler & Sonnet (2016), it was found students overcome misconceptions when teachers had both high subject-matter knowledge and high knowledge of student' misconceptions. Teachers who know their students' misconceptions are more likely to increase their students' science knowledge than teachers who do not. To do this, the teacher does not just need to be a master of the content, but also in how students learn topics (Sadler & Sonnet, 2016).

Evolution-Related Misconceptions

Some misconceptions about biological evolution develop during learning about evolution, but others stem from purposeful attempts to misrepresent and undercut society's understanding of evolution. Shtulman and Calabi (2012), list six categories foundational to comprehending biological evolution: adaptation, variation, inheritance, speciation, domestication, and extinction. Student misconceptions in these categories can be, but are not limited to, evolutionary processes, acceptance, and the nature of science. Common misconceptions, such as humans evolved from modern day apes, make learning about evolution a challenging process of changing prior held views (Sinatra et al., 2008). Chi et al. (2012) argued "learners are better equipped to understand direct processes, rather than emergent phenomena"(p.145). Students learn best when they can directly observe concepts, which presents an issue as biological evolution is complex and systematic in nature.

Other common misconceptions about evolution students hold relate to how long the evolutionary process can take to occur. Students have a hard time wrapping their minds around the idea that the Earth is old enough for evolution to have occurred. Over long periods of time, complex features that are results of evolution or changes to an organism's environment will drive natural selection. Additionally, they may think humans and prehistoric animals such as dinosaurs were alive at the same time. Finally, the theory of evolution is commonly questioned using the erroneous belief that evolution is “just a theory” and doesn’t have significant evidence to support it. This misconception is because society’s definition of “theory” more closely aligns with the scientific definition of “hypothesis” or an untested guess rather than the scientific definition of “theory”, which is a well supported explanation of an aspect of the natural world that can incorporate laws, hypotheses and facts, often from multiple disciplines.

Inquiry-Based Learning Cycle

The most common instructional method being utilized to accomplish addressing misconceptions is the inquiry-based learning cycle (Türkmen and Usta, 2007). Inquiry-based learning emphasizes the student's role in the learning process. Students explore topics, ask questions, and share ideas with classmates to help build their understanding, which makes the learning more student-centered rather than teacher-led. Lesson designs are focused around phenomena, which are designed to confront students’ ideas and beliefs and to create cognitive disequilibrium. Longfield (2009) explained students are motivated to begin the processes of accommodation and assimilation, which makes more difficult concepts more intelligible and believable (Longfield, 2009, p. 269).

Next Generation Science Standards and Evolution Standards

The Next Generation Science Standards (NGSS) were developed to prepare students for life after high school, regardless if that was straight into a career, the trades, or higher education. The completed standards were published for use in 2013 (NGSS Lead States, 2013b). The NGSS strive to create non-linear standards for K-12, as it was nearly impossible to get all of the necessary standards into an academic year. This was done to ensure each standard had three dimensions: which are disciplinary core ideas (DCI), crosscutting concepts (CCC), and science and engineering practices (SEP).

The DCI contain important science content across the following disciplines: life science, earth and space science, physical science, and engineering/technology applications. CCC consists of skills students utilize in other aspects of their life. According to the NGSS Lead States (2013a) Appendix G, Cross Cutting Concepts (CCC) include: “Patterns, similarity, and diversity; Cause and effect; Scale, proportion and quantity; Systems and system models; Energy and matter; Structure and function; Stability and change”. Science and Engineering Practices (SEP) are important for building science literacy and help students learn how scientists think. According to the NGSS Lead States (2013a) Appendix F, SEP include: “Asking questions and identifying problems; Developing and using models; Planning and carrying out investigations; Analyzing and interpreting data; Using mathematics and computational thinking; Constructing explanations and designing solutions; Engaging in argument with evidence; Obtaining, evaluating, and communicating information." These dimensions foster inquiry, encouraging students to ask questions and come up with solutions to said questions.

How is Evolution Integrated Into the Next Generation Science Standards?

There are five evolution standards NGSS identifies for students to master by the time they are done with their high school science career. Evolution standards fall primarily under the life science category of DCI. NGSS Lead states (2013a) lists the standards and evidence statements as follows:

- HS-LS4-1. Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
    - Students identify and communicate evidence for common ancestry and biological evolution.
    - Students identify and communicate connections between each line of evidence and the claim of common ancestry and biological evolution.
    - Students communicate that together, the patterns observed at multiple spatial and temporal scales (e.g. DNA sequences, embryological development, fossil records) provide evidence for causal relationships relating to biological evolution and common ancestry.
- HS-LS4-2. Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
    - Students construct an explanation that includes a description that evolution is caused primarily by one or more of the four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

    - Students identify and describe evidence to construct their explanation, including that: i. As a species grows in number, competition for limited resources can arise. ii. Individuals in a species have genetic variation (through mutations and sexual reproduction) that is passed on to their offspring. iii. Individuals can have specific traits that give them a competitive advantage relative to other individuals in the species.
    - Students use a variety of valid and reliable sources for the evidence (e.g., data from investigations, theories, simulations, peer review).
    - Students use reasoning to connect the evidence, along with the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, to construct the explanation.
    - Students use the evidence to describe the following in their explanation: The difference between natural selection and biological evolution (natural selection is a process, and biological evolution can result from that process); and The cause and effect relationship between genetic variation, the selection of traits that provide comparative advantages, and the evolution of populations that all express the trait.
- HS-LS4-3. Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
    - Students organize data (e.g., using tables, graphs and charts) by the distribution of genetic traits over time.

- Students describe what each dataset represents.
- Students perform and use appropriate statistical analyses of data, including probability measures, to determine patterns of change in numerical distribution of traits over various time and population scales.
- Students use the data analyses as evidence to support explanations about the following: i. Positive or negative effects on survival and reproduction of individuals as relating to their expression of a variable trait in a population; ii. Natural selection as the cause of increases and decreases in heritable traits over time in a population, but only if it affects reproductive success; and iii. The changes in distribution of adaptations of anatomical, behavioral, and physiological traits in a population.

- HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations.
  - Students construct an explanation that identifies the cause and effect relationship between natural selection and adaptation.
  - Students identify and describe the evidence to construct their explanation, including: i. Changes in a population when some feature of the environment changes; ii. Relative survival rates of organisms with different traits in a specific environment; iii. The fact that individuals in a species have genetic variation (through mutations and sexual reproduction) that is passed on to their offspring; and iv. The fact that individuals can have specific traits that give them a competitive advantage relative to other individuals in the species.

- Students use a variety of valid and reliable sources for the evidence (e.g., theories, simulations, peer review, students' own investigations).
- Students use reasoning to synthesize the valid and reliable evidence to distinguish between cause and correlation to construct the explanation about how natural selection provides a mechanism for species to adapt to changes in their environment.

- HS-LS4-5. Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.
    - Students identify the given claims, which include the idea that changes in environmental conditions may result in: i. Increases in the number of individuals of some species; ii. The emergence of new species over time; and iii. The extinction of other species.
    - Students identify the given evidence to be evaluated.
    - Students identify and describe additional evidence (in the form of data, information, models, or other appropriate forms) that was not provided but is relevant to the claims and to evaluating the given evidence, including: i. Data indicating the change over time in: a) The number of individuals in each species; b) The number of species in an environment; and c) The environmental conditions: ii. Environmental factors that can determine the ability of individuals in a species to survive and reproduce.

- ○ Students use their additional evidence to assess the validity, reliability, strengths, and weaknesses of the given evidence, along with its ability to support logical and reasonable arguments about the outcomes of group behavior.
- ○ Students assess the ability of the given evidence to be used to determine causal or correlational effects between environmental changes, the changes in the number of individuals in each species, the number of species in an environment, and/or the emergence or extinction of species.
- ○ Students evaluate the degree to which the given empirical evidence can be used to construct logical arguments that identify causal links between environmental changes and changes in the number of individuals or species based on environment.

SEPUP Biology Curriculum Aligned to the NGSS Evolution Standards

The curriculum used in this study is Science Education for Public Understanding Program (SEPUP). SEPUP is aligned to the NGSS and can be utilized as a year long guide complete with learning objectives, formative/summative assessments, and inquiry-based lessons designed to help students get interested in the world around them. The SEPUP curriculum asks students to modify models of their understanding of biological evolution throughout instruction for students to directly see how their ideas have changed over time.

SEPUP is unique for its ability to make biology come alive in the classroom. Students learn about current events and global issues relevant to the content and their own lives. A strength of the curriculum is its ability to highlight human impact on the environment and the planet, and help guide students to come up with ideas on how they can leave a positive impact long after they are gone. From an educator perspective, this curriculum is helpful because it includes a textbook with objectives, analysis questions, and doesn’t read like a traditional textbook. Instead students get instruction directly from reading the textbook as a guide. It begins with a phenomenon story that leads into an activity or lab that students will use to come to their own conclusions through questioning and experimentation. This curriculum also includes all lab and activity materials needed for all units, which makes for less preparation time for educators.

The SEPUP curriculum is a two-year science program, but for the purpose of this research, focus will be restricted to the SEPUP biology section entitled Science and Global Issues- Biology (SGI). The curriculum is aligned to the NGSS. “SGI focuses on the role of science in addressing the needs of modern society and the use of technology in advancing scientific knowledge”(University of California, Berkeley, 2020). The curriculum has students following a guided textbook with activities consisting of phenomena like introductions, inquiry based activities, and analysis questions that can be utilized as a formative assessment. Additionally, this curriculum has lab materials bought in bulk for each unit and are delivered in labeled boxes. The evolution unit within this curricula covers all five evolution standards from the NGSS.

BEL Survey

The BEL Survey developed by Yates and Marek (2011) aimed to “identify teacher and student participants’ knowledge structure and misconceptions about biological evolution” (p.32-33). Yates & Marek (2014) measured the factors contributing to the acquisition of biological evolution-related misconceptions by distributing the BEL Survey to high school Biology teachers.

The BEL Survey asked students to respond if they strongly agree, somewhat agree, somewhat disagree, strongly disagree, or are neutral on 23 statements covering common biological evolution-related misconceptions. Yates & Marek (2014) utilized two methods of scoring student responses. First, they combined responses “strongly agree” and “somewhat agree” to indicate the students' agreeability with the statement. The same was done with the responses “somewhat disagree” and “strongly disagree” to indicate the students' disagreement with the statement. Second, Yates & Marek created a scoring index by means of Likert scaling of responses. Answers to statements indicative of a low acceptance of the evolution concept received low scores while answers to statements indicative of a high acceptance of the evolution concept received high scores. The BEL Survey index score range was 0-115. Yates & Marek (2014) organized the misconceptions into the following categories: (a) science, scientific methodology and terminology (SSMT); (b) intentionality of evolution (IE); (c) nature of evolution (NE); (d) mechanisms of evolution (ME); and (e) evidence supporting evolution (ESE).

The BEL Survey had a Cronbah’s alpha of .848, meaning that the items were internally consistent. What's more, the reliability coefficient did not decrease by more than .014 when any one item was removed, meaning the survey's internal reliability was maintained (Yates & Marek, 2014). The BEL Survey presents an unique opportunity for this study as it identifies misconceptions present in the population, as well as the degree of agreement/disagreement with the misconceptions.

Theoretical Framework

Students enter the science classroom with different ideas or beliefs, which are dependent on their experiences, academically and personally. The idea behind this research is to see how exposure to SEPUP's Biology curricula can affect misconceptions students hold about biological evolution. SEPUP provides varying learning experiences for students that are based on the inquiry learning model. Students are active in the learning process, thus constantly constructing understandings based off of data or information collected. This manner of learning is constructivist in nature.

Educators who hold a constructionist viewpoint on learning assume that students' knowledge is built based on experiences, which influence their comprehension of the related topic. Misconceptions arise when an individual has an opinion or idea based on faulty thinking. In order to fully address the misconceptions students have about biological evolution, it is imperative they go through a conceptual change. Conceptual change is the development of new concepts through knowledge acquisition and restructuring thinking (Özdemir & Clark, 2007). Conceptional change requires the student to go through cognitive dissonance, similar to Piaget's idea of disequilibrium, in which is when the existing belief fails to address important information or problems that arise. Alters and Nelson (2002) emphasized the importance of students changing specific misconceptions in the classroom because of their effect on future learning and scientific literacy.

Piaget's aforementioned learning theory and Thomas Kuhn's (1970) idea of paradigm shifts relate closely to the knowledge-as-theory perspective of conceptual change theory.

Özdemir & Clark (2007) described conceptual exchange, which occurs when the student is dissatisfied with their first conception and abandons it for the scientific conception. The goal is to create a cognitive conflict, in which the student abandons their existing conception for one that is plausible and intelligible. Posner et al. (1982) described a conceptual change within a conceptual ecology perspective, meaning "a learner's conceptual ecology consists of their conceptions and ideas rooted in their epistemological beliefs" (p. 352). Using the perspective of Posner et al. (1982), misconceptions are not only inaccurate, but are constraining to learning. The research question highlights the importance of identifying what misconceptions about biological evolution are present and how those misconceptions change depending on exposure to different Biology curricula. The persistence of misconceptions affects the students abilities to be scientifically literate members of society in the future.

Chapter 3 - Methodology

This study analyzed data using quantitative methods. I utilized quantitative methods to measure the significance of conceptual change using a Likert scale. The data sets collected through quantitative methods can easily be examined from a variety of perspectives (Goertzen, 2017). The data served as support to measuring what misconceptions persist after instruction. The complexity of the data collected and the time it takes to analyze was a limitation of quantitative research (Wisdom and Creswell, 2013).

Participants

This study investigated how exposure to Science Education for Public Understanding Program (SEPUP) Biology curricula addressed student's common misconceptions about evolutionary theory. It assessed how well students accept evolution through misconceptions present after exposure to SEPUP biology curricula through the use of a BEL Survey. The SEPUP curriculum is aligned to the NGSS and for this study was taught at a moderately-sized high school in the Midwest. In the state where this study took place, science instruction must include physical, life, and earth sciences to prepare students to be scientifically literate members of society per the Iowa Department of Education.

School Used in Study

This study took place in a moderate-sized high school located in the Midwest that is a growing school district consisting of 642 students in grades 9-12. The high school is identified as a high performing school (Iowa Department of Education, 2019). It has a 17% minority enrollment and 22% of its students are on free/reduced lunch (Iowa Department of Education). Life science is a required class for all 10th grade students and is currently taught by two instructors. In order to graduate, all students must complete six credits of science, which include Earth Science, Biology, and some level of Chemistry and Physics. Currently, the life science department uses a Biology curriculum entitled SEPUP, which consists of five units (sustainability, ecology, cell, genetics, and evolution) taught over the calendar year. The target unit on evolution was shortened from four weeks to three due to the COVID-19 pandemic.

Materials

Participants were asked to complete the Biological Evolution Literacy Survey (BEL Survey) as a pre and post-test to identify and measure misconceptions about biological evolution (Appendix A). The BEL Survey was originally composed of two sections, the demographics section and the survey section. The demographic section was omitted for this study as the survey requested students to disclose their gender, grade level, and a self-rated score of their knowledge of evolution. The survey consisted of 22 statements about misconceptions related to biological evolution. Each question consisted of a four-point Likert scale that required students to choose their level of agreement/disagreement with each question.

Procedure

Prior to completing the BEL Survey, parents/guardians were notified about the research project following guidelines from the university's Institutional Review Board (IRB). Following guidelines established by the IRB, the survey was not graded nor were identifiers to be collected or stored. Additionally, the students were told that the results would be analyzed prior to the post-test, and due to the minimal risk involved in the research study, permission to use their students' data would be voluntary.

Participants completed the adapted BEL Survey (Appendix A) with 22 questions as a pre and post-test during the Spring 2021 semester. The BEL Survey was administered via Google Forms and emailed out to the students prior to the unit on evolution and once again after the unit was completed. A total of three weeks separated the pre- and post-tests. Data from the BEL Survey were collected from students taught by both instructors using a Google Form. I quantified the students' responses on Google Sheets for easier data analysis. A series of two-tailed t-tests were used to identify any significant differences between student groups. Cohen's d effect size (Cohen, 1992) was calculated for all significantly different results and used to estimate the size of the scale of the observed differences. Values of Cohen’s d would be used in accordance with values described in A Power Primer, for which the effect size values for Cohen’s d will be 0.2, 0.5, and 0.8 which represent small, medium, and large respectively (Cohen, 1992). Action research qualitative analysis was then used to improve teaching practice and to analyze the effectiveness of SEPUP biology at addressing evolution misconceptions. The results from the pre-test served as a baseline of a student's misconceptions prior to exposure to lessons on evolution. After the students completed an assessment on the evolution unit, they completed the BEL Survey as a post-test. In order to address the research question, the post-test also included misconceptions persisted despite instruction depending on the curricula exposure.

I categorized each of the 22 misconceptions into the following NGSS standards: HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5, and no standard (Table 1). They were categorized by if addressing the misconception would bring the students closer to proficiency at any given standard. It was found that 13 misconceptions addressed nearly identical standards, and it was determined that analysis of the data regarding misconceptions would group standards HS-LS4-2 and HS-LS4-5 together as well as HS-LS4-3 and HS-LS4-4 as they would yield identical results. There were three misconceptions that did not fall under an NGSS standard, and were placed into the no standard category, which addressed more science methodology and terminology. These data were analyzed for significance using a dependent measures t-test to determine significant changes between pre and post-test scores of students.

Table 1

BEL Survey misconceptions categorized by which NGSS standard it would help address.

	HS-LS 4-1	HS-LS4 -2	HS-LS 4-3	HS-LS4 -4	HS-LS4 -5
A scientific theory that explains a natural phenomenon can be classified as a 'best guess' or 'hunch.'					
The scientific methods used to determine the age of fossils and the earth are reliable.	X				
The earth is old enough for evolution to have occurred.	X				
Evolution cannot be considered a reliable explanation because evolution is only a theory.					
Evolution always results in improvement.		X	X	X	X
Members of a species evolve because of an inner need to evolve.		X			X
Traits acquired during the lifetime of an organism - such as large muscles produced by body building - will not be passed along to offspring.		X	X	X	X

If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents' generation.		X	X	X	X
Evolution cannot cause an organism's traits to change within its lifetime.		X	X	X	X
New traits within a population appear at random.		X	X	X	X
Individual organisms adapt to their environments.		X	X	X	X
Evolution is a totally random process.		X	X	X	X
The environment determines which traits are best suited for survival.		X	X	X	X
Variation among individuals within a species is important for evolution to occur.		X	X	X	X
'Survival of the fittest' means basically that only the strong survive.		X	X	X	X
The size of the population has no effect on the evolution of a species.		X	X	X	X
Complex structures such as the eye could have been formed by evolution.	X				
Only beneficial traits are passed on from parent to offspring.		X	X	X	X
There exists a large amount of evidence supporting the theory of evolution.	X				
According to the theory of evolution, humans evolved from monkeys, gorillas, or apes.	X				
Scientific evidence indicates that dinosaurs and humans lived at the same time in the past.	X				
The majority of scientists favor evolution over other explanations for life.						

Researcher's Role

Data were collected from classes taught by two instructors. Instructor A (the researcher) had 77 total students while Instructor B had 67 total students. The instructors taught the students using the same curriculum and matched instructional pace. Instructor B has 20 years of teaching experience, while Instructor A has five years of teaching experience. Both instructors attempted to remove bias wherever possible, and utilized their own teaching experiences in addition to the curriculum. It is possible that Instructor B had more examples to back up evolution concepts or address misconceptions compared to Instructor A due to their differences in teaching experience. This had potential to alter these data and was considered in its analysis.

Data Analysis

The data collected in this study were designed to answer the research question: How does exposure to the biology curriculum affect the misconceptions about evolutionary theory held by 10th grade students? A two-tailed t-test determined if there was a significant difference between Instructor A's pre-test compared to Instructor B's. A second two-tailed t-test determined whether the student responses between the pre- and post-test survey data were significant. If the differences are significant, the effect size was calculated using Cohen's d (Cohen 1992). Values of Cohen's d will be used in accordance with values described in A Power Primer, for which the effect size values for Cohen's d will be 0.2, 0.5, and 0.8 which represent small, medium, and large respectively (Cohen, 1992).

Chapter 4 - Results and Discussion

Participants

Data collection took place during the Spring of 2021 and was collected from all 10th grade students. Due to COVID-19, a handful of students took these tests from home via virtual learning. The instructor directed the students to take the tests online, and closed the availability to the tests afterwards. All of the survey results were combined together and analyzed as a whole regardless of where the students completed the survey.

Curriculum Modifications

Due to the time constraints associated with the COVID-19 pandemic, some lessons were omitted from the curriculum sequence in this study. I omitted lessons that were review or additional practice for a concept already covered in previous lessons. The lessons from the SEPUP curriculum that were taught included "Human Activities and Biodiversity", "Geologic Time", "Darwin and the Development of a Theory", "Using Fossil Evidence to Investigate Whale Evolution", "What is a Species", "Natural Selection", and "The Processes and Outcomes of Evolution." Due to these strategic omissions related to time constraints, this study cannot make conclusions based on the entirety of the evolution unit as outlined in SEPUP biology.

Results

The first task was to compare the results to determine if there were any significant differences between the student populations taught by each instructor. Students taught by

Instructor A had a pre-test mean score of 2.86 and a standard deviation of 0.97, whereas the students taught by Instructor B had a mean score of 2.84 and a standard deviation of 0.89 (Table 2). A two-tailed t-test yielded a pre-test p-value of .62 with an effect size of 0.02. Instructor A had a post-test mean score of 3.02 and a standard deviation of 0.97 while Instructor B had a mean score of 2.93 and a standard deviation of 0.94. A two-tailed t-test yielded a post-test p-value of .02 with an effect size of 0.09. These results indicate that there were no significant differences between the students taking 10th-grade Biology from either instructor prior to instruction, and so the data were aggregated together for subsequent analysis.

Table 2

Comparison of Instructor A and B's pre and post-test scores.

	Instructor A (n=77)		Instructor B (n=67)			
	Mean	Standard Deviation	Mean	Standard Deviation	p	d
Pre	2.86	0.97	2.84	0.89	.62	0.02
Post	3.02	0.97	2.93	0.94	.02	0.09

I matched the misconceptions from the BEL Survey to the five NGSS Evolution standards together with a category entitled "No Standard" (Table 1). The No Standard category was created for the three misconceptions in the BEL Survey that could not be matched to a specific standard from the NGSS. Pre-test student responses associated with standard HS-LS4-1 had a mean of 2.82 and a standard deviation of 1.02 and a post-test mean of 3.07 with a standard deviation of 0.98 (Table 3). Grouped standards HS-LS4-2, HS-LS4-5 had a pre-test mean score of 2.82 and a standard deviation of 0.92, and a post-test mean of 2.88 with a standard deviation of 0.97. Pre-test student responses associated with grouped standards HS-LS4-3, HS-LS4-4 had a mean of 2.85 and a standard deviation of 0.92, and a post-test mean of 2.90 with a standard deviation of 0.97. No-Standard had a pre-test mean of 2.89 and standard deviation of 0.84, and a post-test mean of 3.12 with a standard deviation of 0.86.

Table 3

Comparison of misconceptions categorized by NGSS standard for pre and post-test scores.

	Pre		Post			
	Mean	Standard Deviation	Mean	Standard Deviation	p	d
HS-LS4-1	2.82	1.02	3.07	0.98	<.001	0.25
HS-LS4-2, HS-LS4-5	2.82	0.92	2.88	0.97	.06	0.06
HS-LS4-3, HS-LS4-4	2.85	0.92	2.90	0.97	.17	0.05
No Standard	2.89	0.84	3.12	0.86	<.001	0.28
Total	2.85	0.94	2.98	0.96	.03	0.13

Two-tailed t-tests compared the results from the pre- and post-test. The two-tailed t-tests yielded p-values <.001 for both HS-LS4-1 and No Standard and the effect sizes were 0.25 for HS-LS4-1 and 0.28 for No Standard. The grouped standards of HS-LS4-2, HS-LS4-5 had a p-value of .06 while HS-LS4-3, HS-LS4-4 had a p-value of .17. The combined pre-test student responses had a mean of 2.85 and a standard deviation of 0.94, while the combined post-test student responses had a mean of 2.98 with standard deviation of 0.96. A two-tailed t-test compared the combined misconceptions before and after instruction, and it was found that the p-value was .03.

Discussion

For each instructor, the results from the pre-test were compared to assess whether the student populations held different misconceptions prior to instruction. All students were required to take the tests, therefore no students were excluded. Instructor A had 77 students with an average pre-test score of 2.86 and a standard deviation of 0.97. Instructor B had 67 students and average pre-test score was 2.84 with a standard deviation of 0.89. The standard deviations from both groups of students was low, which indicated that the student scores from both instructors clustered close to the mean (Table 2). The high p-value ($p = .62$) on the pre-test suggested that the students in both groups held similar misconceptions when they started the unit on evolution. Therefore the students could be considered one group of similar students, rather than two different groups. This made data analysis run smoother as it could be assumed that they all began in the same spot in regards to their understanding of biological evolution.

Instructor A's average post-test score was 3.02 with a standard deviation of 0.97, while Instructor B's average was 2.93 with a standard deviation of 0.94. The p-value for the post-test was .02, which meant that Instructor A and B's students were statistically different after instruction. Cohen's d value measured the effect size of this statistical difference to be 0.09, which means that although the instructors' students were statistically different after instruction, it was not by much. The effect size was small, which means that the shifts in student beliefs would be difficult for a classroom instructor to observe. The small, yet significant difference between the post-tests could be due to Instructor B not familiarizing themselves with the BEL Survey misconceptions prior to instruction. It is possible that Instructor A, being more familiar with the BEL Survey, inadvertently placed more focus on the misconceptions addressed within the lessons.

There was a statistical difference between the pre- and post-tests regarding standard HS-LS4-1 and No Standard. HS-LS4-1 and No Standard both had p-values $< .001$ (Table 3). Cohen's d value measured the effect size of this statistical difference for HS-LS4-1 to be 0.25 and 0.28 for the No Standard category. This means that the effect size was small and that the difference between pre- and post-test scores would be hard for the instructor to observe. The lessons covered in the SEPUP evolution unit focused primarily on the lines of evidence that support the theory of evolution, which fall in line with HS-LS4-1 and No Standard categories. HS-LS4-1 asks students to support the theory of biological evolution using empirical evidence and the misconceptions that fall under the No Standard category focus on defining a theory in science. A theory is a well-substantiated explanation of an aspect of the natural world that is supported by multiple lines of evidence. Knowing this, it is reasonable to conclude that the data shows significant differences in students learning from pre- to post-test as there were multiple instances within the evolution unit where students could build understanding and comprehension on these topics.

There was no statistical difference between the pre and post tests regarding the combined standards of HS-LS4-2, HS-LS4-5 and HS-LS4-3, HS-LS4-4. The combined standards of HS-LS4-2 and HS-LS4-5 had a p-value was .06 while HS-LS4-3, HS-LS4-4 p-value was .17. Cohen's d value measured the effect size of the combined standards of HS-LS4-2, HS-LS4-5 and HS-LS4-3, HS-LS4-4 to be 0.06 and 0.05 respectively. This means that although the instructors' students were not statistically different after instruction, it was by a small degree. The lessons in the SEPUP evolution unit had less focus on applying concepts of statistics and probability to support explanations of evolution (HS-LS4-3). Although the evidence for evolution was covered extensively in the lessons, the data shows that students had a harder time comprehending concepts related to the potential for a species to increase in number, heritable genetic variation of individuals in a species due to mutation/sexual reproduction, competition for limited resources, and the proliferation of those organisms that are better able to survive and reproduce in the environment.

Aggregating the data from all of the standards yielded a significant difference ($p = .03$) between the pre-and post-test with a small effect size ($d = 0.13$). There is a significant difference between pre- and post-test scores on biological evolution misconceptions after exposure to SEPUP biology. When breaking down the misconceptions into their respective standards, it was found the most significant difference came with those misconceptions not assigned to a standard and that of HS-LS4-1. The other categories containing the remaining evolution standards did not show a significant difference in the pre- and post-scores, but the small effect size means that they are narrowly different. It should be noted that Instructor B has been teaching for 20 years compared to Instructor A's five years, therefore it is possible that they were able to provide additional examples or stories to assist in students comprehension of evolution concepts.

From these results, it can be concluded that exposure to the modified SEPUP biology curriculum impacted students' comprehension of biological evolution, even though the small effect size means that the shifts in student beliefs would be difficult for a classroom instructor to observe. SEPUP biology's focus on the role of science in addressing the needs of society and technology allowed students to address the misconceptions outlined in the BEL Survey. Educators that utilize the modified SEPUP biology curriculum can be confident that it will address common misconceptions associated with biological evolution. If educators are concerned about the standards that showed no significant difference while utilizing the SEPUP evolution unit, they should be able to add in supplemental materials to account for the difference or specifically address the associated misconceptions within that standard grouping during instruction. The addition of their own understanding of evolution misconceptions and content knowledge will have an additive effect on these data, as noted by Sadler & Sonnet (2016).

Limitations

One of the limitations of this study was that it was conducted during the COVID-19 pandemic. The most notable aspect of this limitation was that some students were virtual during the time of the pre- and post-tests. Virtual students could not be as active in their participation, and may have opted not to participate during discussions as much as in person students. The curriculum was followed as effectively as possible given social distancing guidelines and quarantining of students. Hands-on activities were removed and replaced with similar virtual labs and handouts for students to participate in regardless if they were in person or not. Students that were virtual were held to the same standards as those that were in person. It is possible that if this study was conducted during a non-COVID-19 year, the results could be different.

COVID-19 reduced the amount of face-to-face interactions between the instructors and the students. For a majority of the school year, the high school ran on a hybrid schedule to reduce the probability of exposure to the virus. This had students attending half days in person with their teachers, and at home for asynchronous learning during the other half. There was no guarantee that students were completing the work the instructors assigned as homework, which impeded instructional time significantly. Several units of instruction in the Biology class were shortened, including Evolution and Taxonomy. I omitted lessons from the Evolution unit that were review or additional practice for a concept already covered in previous lessons.

Student-teacher relationships were lower than an average year as a result of the pandemic. Instructors, and students, were advised to stay 6-feet from the students at all times and therefore could not interact in a normal personal manner. As stated above, this also impacted the ability to conduct hands-on activities that would normally have taken place according to the curriculum. This atmosphere could have made it easier for misconceptions to persist in the classroom as confusion and a lack of interaction made it harder for students to speak out.

Further Research

Does exposure to the entirety of the SEPUP biology curriculum significantly change the results of the study? The lessons that were removed due to COVID-19 and time restraints were review and extra practice/exposure of concepts regarding evolution. If a new study was conducted with the entirety of the SEPUP biology curriculum in regards to evolution, it is possible that all five evolution standards would show significant differences between pre- and post-tests. This cannot be confirmed without conducting the experiment again with all of the lessons from the evolution unit.

Would analyzing pre- and post-test scores based on the misconceptions be a more accurate interpretation of SEPUP biology's ability to address misconceptions? I categorized misconceptions by the NGSS standard(s) based on their content knowledge and prior work with the standards. Grouping of the standards made data analysis more manageable and helped identify which standards may need to be reassessed if misconceptions persisted after instruction. If I instead measured the significance between pre and post-test scores based solely on the misconceptions, they would need to run a t-test for each of the 22 misconceptions and then interpret the data from there. Modifications could be made in addition to the formal curriculum so that whatever misconceptions were found not to have a significant change between pre and post-test scores would be addressed in the unit.

Conclusion

The goal of this study was to investigate how exposure to the SEPUP biology curriculum affects misconceptions about evolutionary theory among 10th graders enrolled in Biology. This, in turn, could help measure the degree of conceptual change about evolution in that demographic. The results of this study are outlined in Chapter 4 of this study. Overall, according to the two tailed t-test conducted for the degree of change in misconceptions before and after instruction, there was a significant change in student misconceptions about evolution after exposure to the SEPUP curriculum ($p=.03$). This leads to the conclusion that the SEPUP curriculum does its job at addressing common misconceptions students have about biological evolution. The p-value of .03 is less than the cutoff value for statistical significance of $p=.05$.

Further data analysis into the standards that would address the misconceptions identified in the BEL Survey found that the categories No Standard and HS-LS1-1 had significant differences between pre and post-test scores. The combined standard groupings of HS-LS4-2, HS-LS4-5 and HS-LS4-3, HS-LS4-4 showed no significant difference between pre- and post-test scores but the effect size was small. The research question can be answered as written. Students who were exposed to the SEPUP biology curriculum for evolution decreased the number of misconceptions.

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Appendix A

BEL Survey adapted from (Yates and Marek, 2011)

For the following items, please indicate your agreement/disagreement with the given statements using the following scale:

Strongly Disagree	**Somewhat Disagree**	**Somewhat Agree**	**Strongly Agree**
1	2	3	4

1. A scientific theory that explains a natural phenomenon can be classified as a ‘best guess’ or ‘hunch.’
2. The scientific methods used to determine the age of fossils and the earth are reliable.
3. The earth is old enough for evolution to have occurred.
4. Evolution cannot be considered a reliable explanation because evolution is only a theory.
5. Evolution always results in improvement.
6. Members of a species evolve because of an inner need to evolve.
7. Traits acquired during the lifetime of an organism - such as large muscles produced by body building - will not be passed along to offspring.
8. If webbed feet are being selected for, all individuals in the next generation will have more webbing on their feet than do individuals in their parents’ generation.
9. Evolution cannot cause an organism’s traits to change within its lifetime.
10. New traits within a population appear at random.
11. Individual organisms adapt to their environments.

For the following items, please indicate your agreement/disagreement with the given statements using the following scale:

Strongly Disagree	**Somewhat Disagree**	**Somewhat Agree**	**Strongly Agree**
1	2	3	4

12. Evolution is a totally random process.
13. The environment determines which traits are best suited for survival.
14. Variation among individuals within a species is important for evolution to occur.
15. ‘Survival of the fittest’ means basically that ‘only the strong survive.”
16. The size of the population has no effect on the evolution of a species.
17. Complex structures such as the eye could have been formed by evolution.
18. Only beneficial traits are passed on from parent to offspring.
19. There exists a large amount of evidence supporting the theory of evolution.
20. According to the theory of evolution, humans evolved from monkeys, gorillas, or apes.
21. Scientific evidence indicates that dinosaurs and humans lived at the same time in the past.
22. The majority of scientists favor evolution over other explanations for life.