Using Simulations to Support Undergraduate Elementary Preservice Teachers' Biological Understanding of Natural Selection

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ABSTRACT

Natural Selection is prevalent throughout life science learning standards across K-12 contexts. Additionally, undergraduates who are interested in the fields of biology and education must also be well informed on the topic, as it is foundational to some biology research and necessary to touch upon within elementary and secondary classrooms. This pilot study explores the understanding of undergraduate preservice teachers' understanding of evolution mediated by a simulation called SEPUP, which explains evolution within generations of bird populations. By utilizing this simulation, we were able to identify how students engaged with a simulation to think about natural selection. Through analyzing student artifacts, findings suggest that employing a simulation to teach natural selection afforded students' a positive learning experience which likely could not have been easily achieved otherwise. This work provides recommendations for technology usage (e.g. creating meaningful reflection questions which target content) and development (e.g. ensure simulations provide a clear scope and scale around time) for evolution simulations.

Keywords: natural selection; undergraduate learning; simulations

Introduction

Natural selection is a staple learning standard taught at all grade levels. Despite this, some students may lack a baseline understanding of it. The concept of natural selection is first introduced to elementary students in third grade as they begin to explore the concepts of inheritance, variation, and diversity in traits. These concepts, pursuant to Standards 3-LS4-2 Biological Evolution: Unity and Diversity as well as 3-LS3-1 Heredity: Inheritance and Variation of Traits (NGSS, 2013), begin to form the base of a structure that ultimately lends itself to understanding pivotal biological concepts and theories. In order to explore comprehension of this topic at the college level, we employed the use of a simulation encompassed within a classroom session focused on science and technology learning. This pilot study aimed to measure the practicality of using a web-based simulation in order to instruct a group of undergraduate preservice science educators regarding the topic of natural selection, answering the research question:

> How do elementary preservice teachers conceptualize natural selection when engaging with a simulation?

Background Literature

There are three main facets of science education literature that we have identified in contributing to the background of this study: science education as it relates to natural selection, preservice elementary teachers' misconceptions about evolution, and the use of simulations to garner scientific understanding.

Science Education in Biology & Natural Selection

Understanding natural selection is not limited to primary or secondary educational levels—it is a fundamental pillar of understanding biology, and this is carried into the collegiate level of teaching, as well. Research has shown that undergraduate students still harbor misconceptions surrounding natural selection even after taking one semester of introductory biology in college (Nehm and Reilly, 2007). The results of this study determined that although 99% of the students enrolled in the course had heard of natural selection or had been taught it previously, only a few students were able to effectively provide an accurate definition of these concepts. This is important to note, as many of these students will progress onto teaching in science classrooms prior to identifying their own misconceptions. Nehm and Reilly (2007) discuss the importance of capturing the variation in experiences that individual students may have, and this assists in providing greater insight into what students think. Studies have been conducted with regard to formative assessments and how to “squash” misconceptions regarding natural selection (Furtak, 2012). Studies have demonstrated that biology majors share several misconceptions about natural selection, despite having previously taken biology courses (Furtak, 2012; Nehm & Reilly, 2007). Thus, it is important to address these misconceptions at various grade levels, including working with preservice science educators to ensure they are comfortable cultivating the concepts they are tasked with teaching.

Natural selection learning has been studied extensively in populations of students majoring in biology, however there is a lack of literature examining preservice teachers' conceptions and understanding of natural selection (Nehm & Reilly, 2007; Furtak, 2012; Sickel & Friedrichsen, 2015). As some teachers progress onto teaching general science courses, it’s essential to address these misconceptions at all grade levels. Further research could be conducted to assess the extent of the knowledge preservice teachers possess when fully matriculating into the lead educator in a classroom.

Preservice Teachers’ Experiences in Evolution

In the realm of teaching evolutionary concepts at both an introductory (e.g. the standards set forth by the NGSS for elementary studies) as well as the collegiate level (e.g. course standards for teaching preservice science educators), multiple methods have been employed to demonstrate the concept of natural selection. One such method is the use of simulations, which is the method that we have chosen for exploring evolution learning in preservice science teachers. Research has shown that teachers who do not fully grasp natural selection and evolution are likely to pass down that misunderstanding to the students they teach, no matter the grade level (Schrein et al., 2009). In this study conducted by Schrien et al. (2009), teachers were asked to create their own concept maps about evolution. The teachers were given a focus question and were encouraged to include 15-20 words or short phrases in their concept map. Between all of the participants, three conceptual categories were identified: misconceptions about Darwin’s discoveries, mechanisms of evolutionary change, and the meaning of commonly used terms in evolutionary biology (Schrein et al., 2009). These misconceptions surrounding evolution may permeate into the classroom, highlighted through elementary classroom studies (Emmons et al., 2017). Emmons et al. (2017) highlights the misconceptions about natural selection that elementary students may have learned during their time in the classroom. While natural selection is considered a learning standard for grades 6-12, elementary students can quickly develop misconceptions surrounding natural selection at a young age (Emmons et al., 2017). If these misconstrued ideas are formed when a student is still in elementary school, they may carry this with them throughout their educational journey.

Natural selection is a unit that both teachers and students struggle with, as students need more tangible models to understand the complexity of the subject at hand (Sickel & Friedrichsen, 2015). By employing the use of a simulation, we hope to further enhance preservice teachers’ understanding of natural selection.

Using Simulations to Teach Biology Concepts

Research has demonstrated science cognition and learning are improved when students are given the opportunity to interact with their environment while also participating in inquiry-based science interventions (Alexander & Russo, 2010; Chen et al., 2014; Dyer & Elsenpeter, 2018). By allowing students to explore the natural environment around them, such as with Alexander and Russo’s (2010) work, students demonstrated more engagement and understanding of scientific concepts in relation to nature. This idea of providing students with real life, interactive examples can be transposed onto other fields within the sciences. Simulations are an incredibly useful tool to demonstrate concepts that would otherwise be impractical or unethical to perform in the real world (Ameerbakhsh et al., 2019).

Problem-based simulations have also been developed over the years to introduce students to real-world situations, such as Kumar and Sherwood’s (2007) study measuring a group of science education students’ skills after studying water quality. Research has shown that simulations are beneficial in situations where the phenomena occurring is difficult to visualize, such as generational change and population shifts over thousands of years. However, without proper scaffolding, simulations can also cause confusion for students who do not have a baseline understanding of the concept at hand (Sickel & Friedrichsen, 2015). This highlights the importance of a simulation with clear instructions and descriptions in order to provide the necessary background information that a student may need. For this study, we chose the Science Education for Public Understanding Program (SEPUP) simulation on

Natural Selection, found at the web address https://sepuplhs.org/high/sgi/teachers/evolution_act11_sim.html). SEPUP is a non-profit, research-based program housed at the University of California, Berkeley. Several researchers have tested the viability of this simulation, as well as the National Science Foundation, and it is considered a valuable tool for teaching and learning scientific concepts (Nagle et al., 2016; National Science Foundation, 1997; Ogens & Koker, 1995). Our reasoning for choosing this simulation was the functionality on multiple computer systems as well as the accessibility and simplicity of the program. Over several years, this simulation has received robust positive feedback from researchers and educators alike and can be applied to a variety of grade levels. By employing this pilot study, we hope to contribute further to the literature improving the quality of tools available to teach preservice science educators who plan on working in general science classrooms.

Methods

Students were asked to participate in learning about natural selection through an online simulation. Worksheets were used that asked questions about the data from the simulation and about natural selection. Students were asked to document and reflect about their experience both during and after the simulation. These artifacts capture the diversity of ways individuals within a group experience this phenomenon (Lister et al., 2004). Additionally, observational notes were taken throughout the class period. This assisted in identifying the connections between the different groups of students, and how or why they did or did not learn new concepts about natural selection.

We utilized a phenomenological framework to analyze our data and to investigate the scientific experience of the participants. The focus of a phenomenographic study is not based on the individual experiences of the subject involved, but rather a comprehensive understanding of how the collective subjects experience any given phenomenon (Bodner & Orgill, 2007). Phenomenography is a powerful tool to interpret data received from student responses. Phenomenography assists researchers in identifying individual learning differences within an experimental sample, and this helps paint an overall picture of how students vary in learning about a specific topic. Orgill (2007) provides several examples of chemistry and science education studies based in the methodological framework of phenomenography. There are such examples as Aguirre & Haggerty's (1995) study researching preservice teachers' conceptions of learning. These researchers were interested in learning about how preservice teachers described their learning experience over the course of the academic year. Other studies, such as Yung's (2001) work, were interested in learning more about biology teachers' conceptions of fairness in implementing school-based assessments. This study considered that all biology teachers may approach school-based assessments in various ways, and it is important to how their conceptions were formed. Orgill's (2004) work, however, details the primary reason why we were interested in using phenomenography as a framework—Orgill states that they were interested in the experience that instructors and students had using analogies in biochemistry. Orgill was not concerned with their own experiences in chemistry education, but instead were concerned of the students and instructors they worked with (Orgill, 2004). By focusing on the multiple ways that students may experience this content, phenomenography may be used to effectively describe how each student may vary in their own experience of learning.

Participants & Context

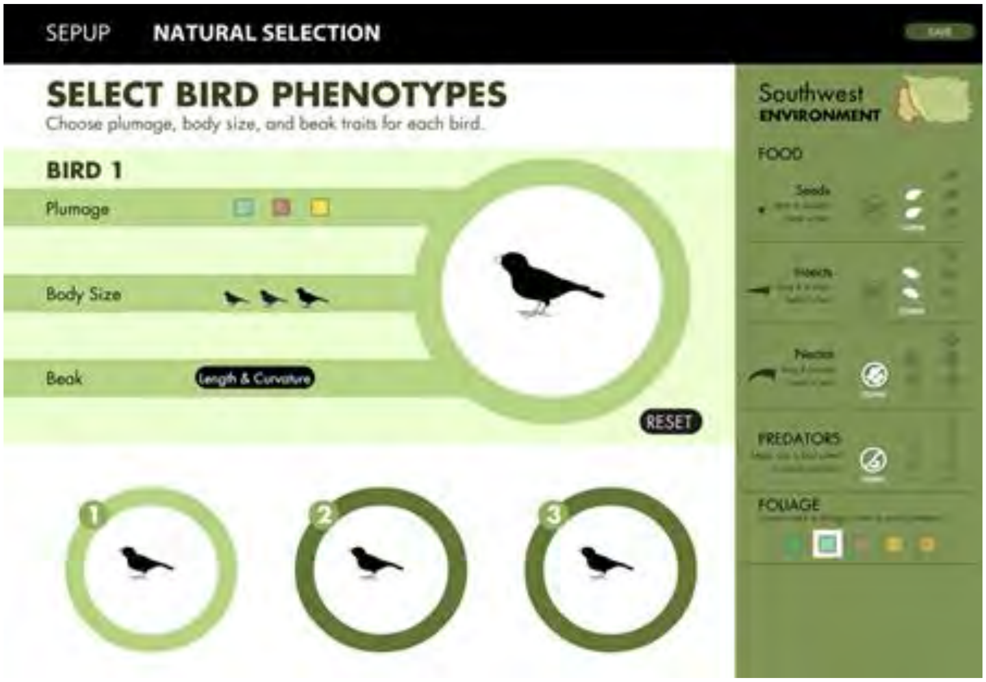
Participants in this study were 25 elementary preservice teachers enrolled in a teacher education program at a large southwestern university. After all artifacts were submitted, only 14 students submitted all documents and were considered for this study. This university is a Hispanic and minority-serving institution, with a population of elementary preservice teachers reflective of the local population. The undergraduate students were Juniors and Seniors, enrolled in a 16-week science methods course typically required the semester before student teaching.

Simulation Description and Classroom Intervention

We began the intervention by outlining the benefits and drawbacks of using technology in the classroom. The students were then asked about their knowledge of natural selection, and answers were given regarding overarching concepts such as Darwinism and "survival of the fittest." We instructed students to record their thoughts and feelings regarding the discussion and the use of technology throughout the class period, including before, during, and after the simulation. Additionally, students were asked to record their answers regarding the simulation on a worksheet (Appendix).

Figure 1.

Student view of SEPUP Simulation.



Environment information, including food, predators, and foliage, are listed in the right-hand window.

The simulation begins by having students choose the traits that they would like to see in three different bird populations. These traits are based on computer-generated information regarding food availability in the environment, the color of the foliage in the environment, and any present predators. This information was provided in a sidebar window of the simulation, and descriptions were listed for what would work best for that particular environment (Figure 1).

Students were able to make choices such as beak size and curvature, plumage color, and body size. The different phenotypic choices made by the students influenced the increase or decrease of each bird population on the premise of natural selection. The simulation displays this message prior to beginning.

> "This part of the simulation represents 500,000 years. A bird population exists in the southwestern portion of the island. During this time, mutations may change the fitness of some birds and their descendants in the environment.
>
> Birds with traits that enhance their fitness are more likely to survive and reproduce."

The simulation provides information on the changes in the population every 50,000 years, pausing for students to record their population numbers and observe any changes (i.e. a mutation causes beaks to grow larger, allowing that population access to larger insects). This occurs ten times, providing students with the population numbers up to 500,000 years. Mutations could be randomly introduced by the simulation at every 50,000-year mark. These mutations could change any of the three phenotypic traits, and lead to increasing, decreasing, or not affecting fitness. The students were asked to write down both their starting bird population numbers as well as their final population numbers. Students were provided ~10 minutes of guided, step by step instruction to ensure they understood the functionality of the simulation. The students created a table to record their results over time and took note of changes that occurred. Once everyone reached the 500,000-year mark, the students were asked to compare and contrast their starting populations to their final populations with other students in the class. The students recorded their thoughts on their respective worksheets, followed by answering the discussion questions once the simulation was complete. Next, students were allowed to start the simulation again, and freely investigate how their bird population evolved on their own for ~ 20 minutes, as instructors circulated around the room, only answering questions as needed.

Data Collection

Three student artifacts were collected: a worksheet focused on the content of the simulation (Figures 2 & 3), reflection answers collected in student notebooks and during the posttest (Figures 4 & 5), and observational notes from the classroom group.

discussion, taken as needed. Students were asked to answer questions regarding the simulation itself, as well as documenting any observations or instances of increased understanding during the simulation. Students were also asked to interact with other student groups in order to compare and contrast their different populations. Complete data was collected from 14 of the 25 students who participated in this study.

Student Worksheets

The simulation was accompanied by a modified worksheet from the unit SEPUP: Science & Global Issues – Natural Selection. This worksheet contained questions regarding natural selection that were to be answered throughout the class (Appendix A).

Student Reflections

After using the simulation and completing the worksheet, students were asked a series of questions with the intent to discover their understanding of the simulation. Figures 4 and 5 highlight student responses within their notebooks, while the questions below were answered by students once the simulation was completed.

1. Today we explored the implementation of technology within the classroom in order to assist with science learning by the use of simulations. Did you find this beneficial in solidifying your knowledge of natural selection, and why? What worked for you personally and for your group overall?

2. Using technology to introduce new concepts is beneficial if it is applicable to different classrooms.

Figure 2.

Student Worksheet.

Environmental Condition	Bird Phenotype Best Suited
Seeds	Short & Straight beak is best
Edible Insects	long & Straight beak is best
Nectar	long & Curved beak is best
Predators	larger size best suited to avoid Predators
Foliage Color	Closest Match to foliage is to avoid Predators

Student answers regarding the best bird phenotype based on the environmental conditions.

Figure 3.

Student Worksheet.

1. Discuss how the bird populations changed over the course of the 500,000 years. For example, what types of mutations occurred? Under what circumstances were the offspring more or less fit as a result of the mutation?

Bird 1 and 2 remained fairly constant, Bird 3 thrived and grew steadily in number over time. Bird 1's beak decreased in size and Bird 3's body decreased in size. No mutations for bird 2

2. Were your ideas about the fitness of each phenotype you selected correct? Explain why or why not.

Yes, we chose our traits based on food and predators shown. None of our birds died out.

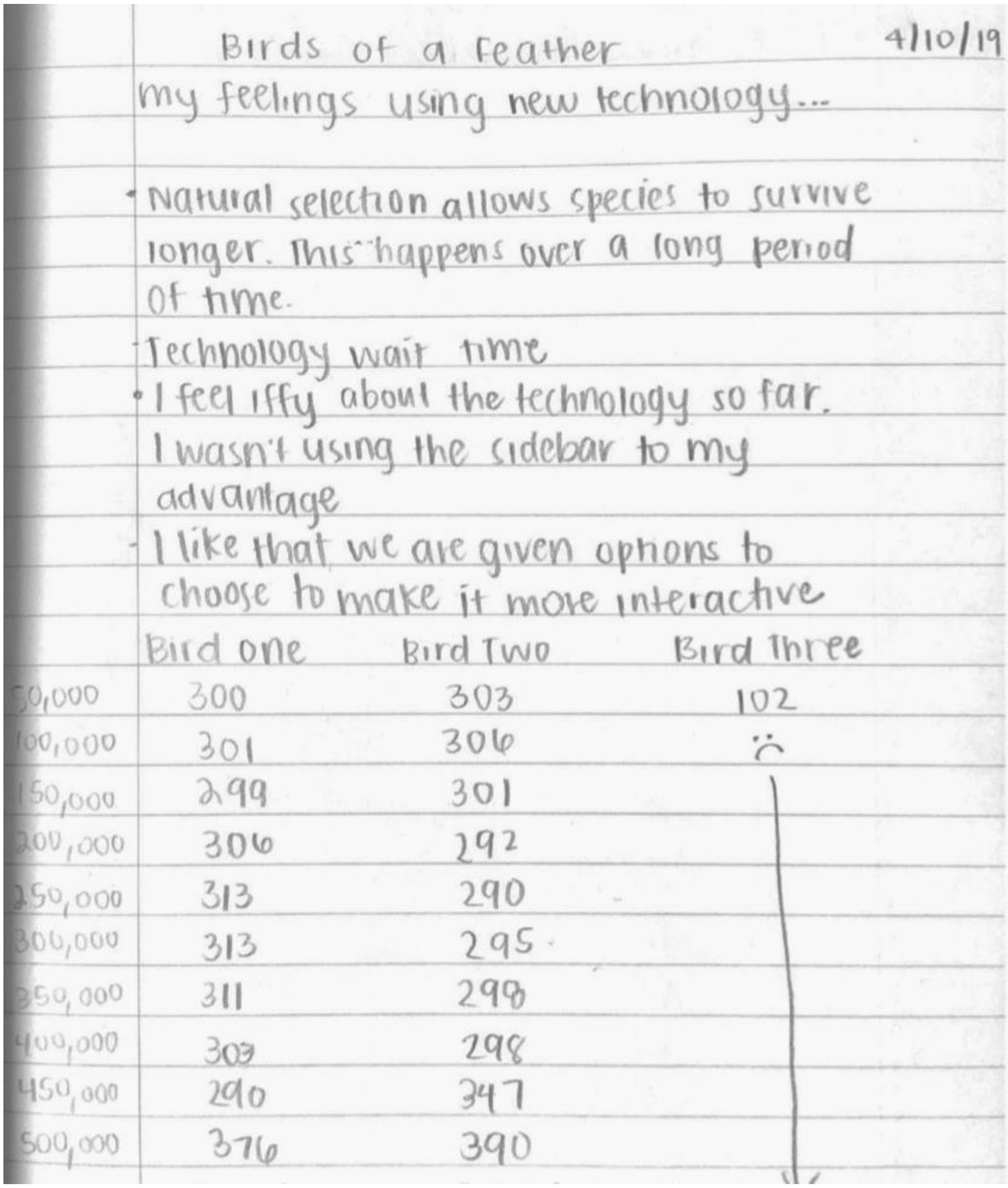
3 Compare how the bird populations changed compared to the bird populations of another group of students. There simulation should have yielded different results. Record the similarities and differences you notice.

Our Bird 3 decreased in size and thrived and another group's bird who decreased in size also thrived. Color is Irrelevant

A student's written answers to the discussion questions

Figure 4.

Responses from Student 2.



Birds of a Feather 4/10/19

my feelings using new technology...

• Natural selection allows species to survive longer. This happens over a long period of time.

Technology wait time

• I feel iffy about the technology so far. I wasn't using the sidebar to my advantage

- I like that we are given options to choose to make it more interactive

	Bird one	Bird Two	Bird Three
50,000	300	303	102
100,000	301	306	☹
150,000	299	301	
200,000	306	292	
250,000	313	290	
300,000	313	295	
350,000	311	298	
400,000	303	298	
450,000	290	347	
500,000	376	390	

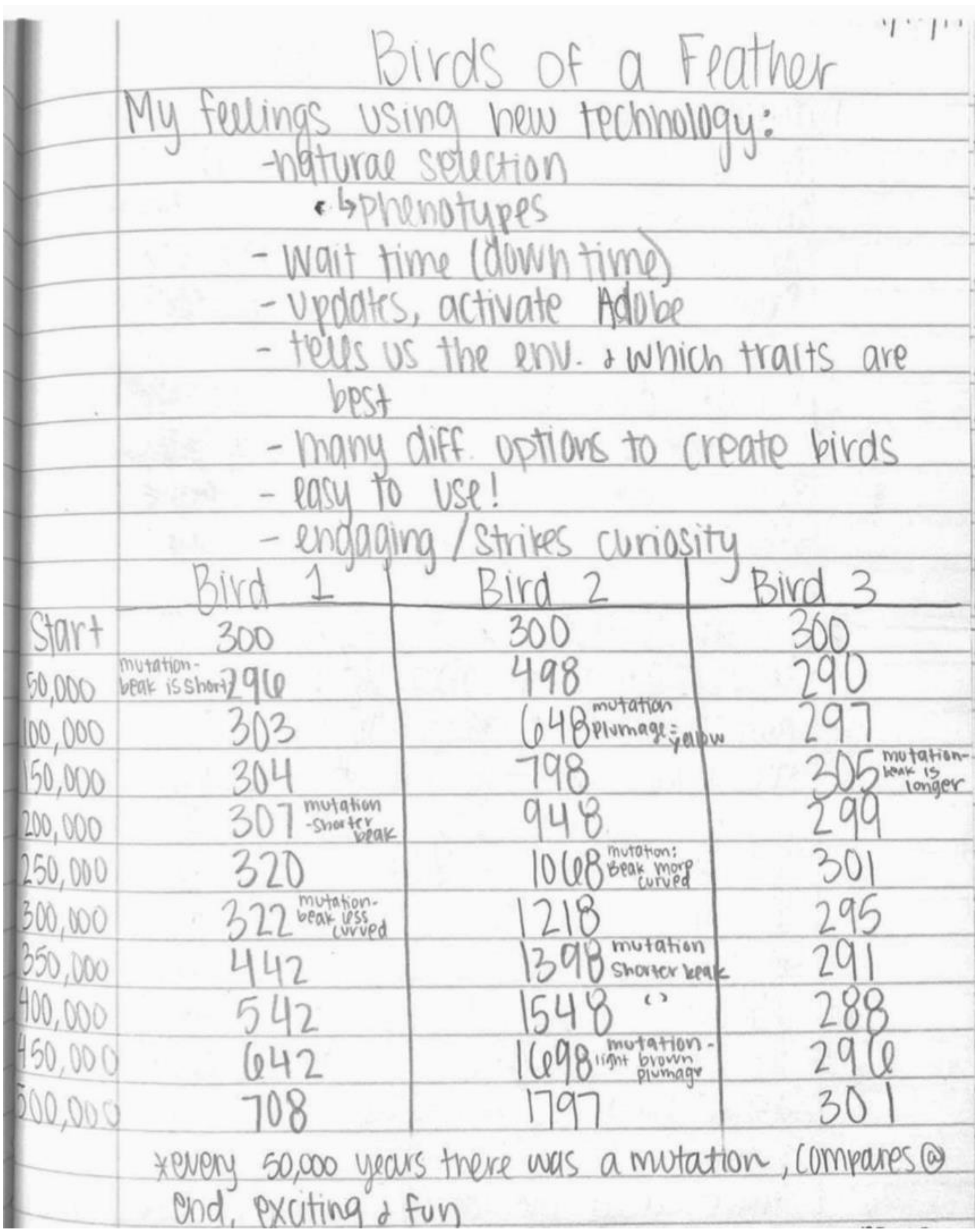
How would you potentially implement this strategy within your own classrooms? (You are not limited to this specific simulation—instead, focus on the use of simulations to teach relevant concepts overall). What parts do you think would be beneficial for your classes, and what would you change?

Data Analysis

Responses to the modified natural selection worksheet were recorded and analyzed for instances of understanding natural selection and the variation of evolutionary traits over time. Responses from students contained within the student reflection papers were qualitatively coded via open coding using MAXQDA software for Macintosh systems. Instances of positive technology experience and enhanced learning were recorded. Analyzing the reflection papers assisted in highlighting the ways in which different students experience different concepts.

Figure 5.

Responses from Student 3.



Birds of a Feather

My feelings using new technology:

- natural selection
  - ↳ phenotypes
- wait time (down time)
- updates, activate Adobe
- tells us the env. & which traits are best
- many diff. options to create birds
- easy to use!
- engaging / strikes curiosity

	Bird 1	Bird 2	Bird 3
Start	300	300	300
50,000	mutation- beak is short 296	498	290
100,000	303	648 mutation plumage = yellow	297
150,000	304	798	305 mutation- beak is longer
200,000	307 mutation -shorter beak	948	299
250,000	320	1068 mutation: beak more curved	301
300,000	322 mutation- beak less curved	1218	295
350,000	442	1398 mutation shorter beak	291
400,000	542	1548 "	288
450,000	642	1698 mutation- light brown plumage	296
500,000	708	1797	301

*every 50,000 years there was a mutation, compares @ end, exciting & fun

Findings

First, we will focus on how students conceptualized natural selection. Many students were surprised at the outcome, noting that their initial predictions did not match the outcome of their populations. For the first round of the simulation, one student wrote, "we thought the big bird would survive and he did not. I thought red would survive but it did not. Same with curved beak." They then shared ideas regarding which traits conferred a higher fitness for their populations and identified what phenotypic variations allowed their populations to survive. Some students noted how the environment set the tone for the direction of the mutations, while some mutations were entirely random. Observational notes demonstrated that when students spoke with other groups they were able to come to the correct conclusion that mutations do contribute to natural selection, thus expanding upon their understanding of natural selection and the processes that act upon populations over time.

Student A, for example, was able to identify when mutations occurred during the simulation and related those mutations to either an increase or a decrease in the population. This demonstrated a level of understanding that was not explicitly outlined in the simulation, which assisted this student in solidifying their knowledge surrounding natural selection. They wrote, "Bird 1 changed size and color because there was a mutation picked up. At 150,000 [years] a mutation made their offspring better mates." Student B drew the conclusion that color was irrelevant in this portion of the simulation, as there were no predators present in the environment, so the birds did not need to blend in with the foliage. During the classroom observation and discussion, they shared this information with their groupmates and the instructors. Since they chose their traits based off of the food and predators shown, the only influencing factor on their population numbers were the traits affecting food acquisition. Additionally, we found that there was variance in students' depth of understanding. While some students reported using the simulation to understand population changes over time, such as describing which populations increased or decreased, other students were able to connect the different phenotypic variations with an increase or decrease of fitness. One student noted the following in their reflection paper:

> "The use of simulations was more beneficial in solidifying my knowledge of natural selection. It was more beneficial because I got to physically see changes overtime, see the mutations, see what characteristics are better than others when it comes to surviving, and it was interactive."

With regard to the use of the simulation itself, student feedback was overwhelmingly positive, with only a few students stating that they didn't understand the material as they felt it was outside of the scope of their classrooms. One student stated:

> "I found the use of simulation more beneficial in expanding my knowledge of natural selection. This simulation was really fun to see what happened to the birds and the explanation that was given about the changes it underwent. We could make guesses about why those changes happened. Generally it was to increase the ability to get food. I thought our bird that was a brown colour and did not blend into the foliage would have died off and it survived. It did not thrive like the other two birds that were green, but it did not go extinct either."

Overall, the discussion was robust, with many students actively engaged in the material and sharing that they were more comfortable with the topic of natural selection after completing this simulation. One student notes the impact of the simulation on their knowledge of natural selection, which was further confirmed by their correct assessment that changes and mutations contribute to natural selection: "Before coming to class I have a very broad idea of natural selection and how it works. I believe all aspects of the lesson contributed to my knowledge." In speaking about applying this simulation to their own future classrooms, this same student wrote that they would like to use this simulation, as "[my students] are able to see the change over years within minutes and have actual representations plus descriptions of the changes/mutations."

We were able to determine that this group of students responded positively to simulations that broke down important evolutionary concepts. The level of student engagement was noteworthy, as one student (Student BC) discussed wanting to continue to use this simulation at home in order to develop their knowledge of natural selection. By analyzing the student responses to both the worksheet and open-ended discussion questions, we were able to gain insight with a small, focused view of the impact of simulations on elementary preservice teachers.

Discussion

Our work further contributes to the existing literature by demonstrating the effectiveness of meaningful, interactive simulations with regard to teaching important biological concepts to elementary preservice science educators. By teaching elementary preservice science educators about the importance of hands on, interactive learning, we may further develop tools that contribute to a larger understanding of biology at an earlier age.

Research focusing on how preservice teachers learn concepts they will eventually be teaching is essential to creating a strong base of educators. Currently, students may be lacking in their knowledge of baseline biological concepts, and efforts must be made to ensure all students are prepared for the educational workforce upon graduation (Nehm & Reilly, 2007). By introducing preservice teachers to the application and benefits of using simulations, we can better prepare them for implementation of these tools within their own classrooms (Ameerbakhsh et al., 2019). With regard to the scientific literature, there are several ways in which this research may contribute: first, it can assist in developing or improving simulations used to teach biological concepts. By asking students to consider the implementation of this at a variety of grade levels, it may open up the possibility of using meaningful, interactive simulations at all stages of classroom-based education.

Second, this research may contribute to improving the teaching of natural selection at a college level. Currently, even biology majors may struggle with properly understanding natural selection (Furtak, 2012; Nehm & Reilly, 2007). If students who are studying this evolutionary theory struggle with misconceptions surrounding it, it is reasonable to assume that preservice science teachers may also struggle with these concepts as well. This research can ideally address these gaps in learning to further assist students with addressing their misconceptions about natural selection.

Third, this project could impact individuals who create simulations and technology surrounding evolution. Teachers have a variety of concepts to cover at a relatively quick pace, so employing the use of an effective simulation may assist in properly teaching an otherwise intangible concept. Participants in this project all enjoyed using the simulation for different reasons-- student responses included terms such as "simple,", "easy to use," "engaging," "fun," and "easy to navigate." Students were able to effectively use the simulation and focus more on the learning aspect of it as opposed to the navigation of the website. Ensuring future simulations attended to these ideas would improve the experience and potentially making students more open to engaging with the content. Having elements of time very clearly accentuated helps students frame the concept of evolution and, being able to watch populations change over time, helped this group of students conceptualize natural selection.

Limitations

The population size of the study is a limiting factor. The classroom had 14 students complete all of the work, so various approaches to conceptualizing natural selection may not all be identified within this group. Additionally, since these students are all preservice science teachers, they have been trained to recognize concepts such as metacognition and other educational scaffolding techniques. These students may be more aware of their own learning, which may either benefit or harm their initial responses to this study. By using phenomenography as a methodological approach, this could potentially mitigate these issues by highlighting the differences in learning styles.

Future Directions.

More research should be conducted to expand upon the similarities and differences present when students experience new concepts such as natural selection. Overall, this research contributes to the improvement of science teaching and learning, further developing tools to enhance science education in the classroom. Further work can be done to measure student responses to a variety of simulations, and whether the concepts learned through these simulations carry over into everyday classroom instruction. Creating a strong foundation and understanding of evolutionary concepts at an early age will prepare students to engage and understand science for years to come.

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Appendix

Lab: Natural Selection

(modified from Sepup: Science & Global Issues – Natural Selection)

Background: In this simulation you will investigate populations of birds living on an island. You will begin by selecting three birds that represent phenotypes for several traits in one population that lives in the southwest portion of the island. You will explore how this population changes over time in the southwest. Then you will explore how the population evolves over long time periods in various environments on other areas on the island.

Activity: Begin by visiting http://sepuplhs.org/high/sgi/teachers/evolution_act11_sim.html to open the simulation. The first simulation represents 500,000 years. During this time, mutations may alter the ability of some birds and their descendants to thrive in the environment. Birds with traits that enhance their fitness are more likely to survive and reproduce. In the southwest, your birds will encounter the environmental conditions listed in the table below. **Fill in the second column of the chart with the bird phenotypes that *you predict* would be are best suited for each of the conditions.**

Table 1:
Environmental Conditions and Bird Phenotype

Environmental Condition	Bird Phenotype Best Suited
Seeds	
Edible Insects	
Nectar	
Predators	
Foliage Color	

Watch the animation and record the changes occur in each bird population over time. **Not every box will be filled in – only when changes occur do you fill in a box.**

Table 2:
Changes in Bird Populations Over Time

	Bird Population One		Bird Population Two		Bird Population Three	
Years	# of Birds	Mutation	# of Birds	Mutation	# of Birds	Mutation
50,000						
100,000						
150,000						
200,000						
250,000						
300,000						
350,000						
400,000						
450,000						
500,000						

Student reflection:

1. Discuss how the bird populations changed over the course of the 500,000 years. For example, what types of mutations occurred? Under what circumstances were the offspring more or less fit as a result of the mutation?

2. Were your ideas about the fitness of each phenotype you selected correct? Explain why or why not.

3. Compare how the bird populations changed compared to the bird populations of another group of students. Their simulation should have yielded different results. Record the similarities and differences you notice.