FEATURE ARTICLE

Using Avida-ED Digital Organisms to Teach Evolution and Natural Selection Benefits a Broad Student Population

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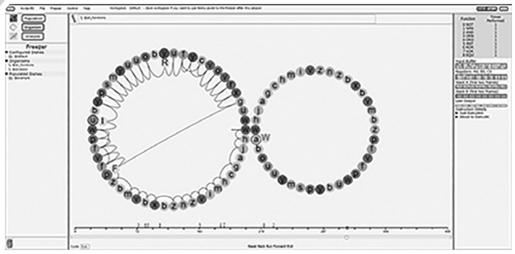

Abstract

In instructional settings, evolution and natural selection are challenging concepts to teach, due to the fact that these topics are difficult to observe in the laboratory or lecture hall. In the past few years, Avida-ED has emerged as an innovative tool for teaching evolutionary principles. It allows students to directly observe effects of evolution by changing different variables, such as environmental conditions and genetic sequences. In our study, we used pretest and posttest questionnaires to investigate the use of Avida-ED in undergraduate coursework. We showed that students demonstrated similar improvement in evolutionary understanding irrespective of major, undergraduate level, sex, or final end-of-course grade. These results reinforce the idea that Avida-ED can facilitate learning of evolution in all student populations.

Key Words: *Avida-ED; evolution; natural selection; digital evolution.*

> *Based on our results, Avida-ED has great potential in being utilized in a variety of different contexts and settings, such as in lower grade levels, community science outreach events, and a great number of high school and undergraduate institutions.*

○ Introduction

The principles of evolution and natural selection continue to be among the more difficult concepts to teach to students. Between the lack of acceptance by the general public (Pobiner, 2016) and the inability to easily observe the process in the lab (Johnson & Lark, 2018), evolution continues to face many hurdles in the classroom. Specifically, previous studies have attempted to identify the factors influencing the acceptance of evolution and have found that an understanding of the nature and process of science is associated with the ability to accept evolution (Dunk et al., 2017). Moreover, all classes are composed of students with different backgrounds, majors, demographics, social attributes, and performance abilities. Many of these parameters have been found to influence students' understanding and acceptance not only of evolution, but also of scientific concepts in general. For example, cultural factors can act as barriers to scientific learning in classroom settings; with appropriate interventions and strategies, these barriers to evolutionary acceptance can be reduced (Green & Delgado, 2021). In addition, a study analyzing the effects of numerous factors on evolutionary acceptance found that parental pressures or attitudes and religiosity were significant predictors of whether students accepted the theory of evolution (Barnes et al., 2017). Furthermore, a 2020 study by Siciliano-Martina and Martina demonstrated that in an online, nonscience-major evolution course, gender as well as psychological and social parameters (including peer or political pressures and negative perceptions of evolution) were significant factors influencing evolutionary acceptance. Interestingly, religious factors were not a significant predictor of evolutionary acceptance in the post-surveys, thus indicating that exposure to an online evolutionary curriculum can potentially reduce barriers to acceptance of evolutionary theory (Siciliano-Martina & Martina, 2020). Clearly, further investigations regarding new methods of teaching evolution in different student populations are vital for increasing the acceptance of evolutionary theory.

Not surprisingly, science majors have a greater acceptance rate and knowledge of evolution than nonscience majors (Partin et al., 2013). Among nonscience majors, as few as 59% have been shown to accept the theory of evolution, and among those, only 6% could accurately explain the principles (Robbins & Roy, 2007). Moreover, nonscience majors and even upper-level biology majors rely heavily on incorrect Lamarckian and teleological reasoning to explain changes in organisms over time (Stover & Mabry, 2007). In terms of sex differences, the literature is not as clear. There seems to be an interaction between the subdisciplines of biology, such as natural

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selection, genetics, and evolution, and question types, such as open-ended, multiple choice, and visual spatial reasoning, such that males outperform females in some of these disciplines and question types, while females outperform males in others (Federer et al., 2016). Other researchers have found that males generally outperform females in science learning, which can be attributed to greater quantitative and visuospatial abilities in males than in females (Halpern et al., 2007). Moreover, the use of various instruments, including the Measure of Acceptance of the Theory of Evolution (MATE) and the Generalized Acceptance of Evolution Evaluation (GAENE), has shown that white and male individuals possessed higher degrees of evolution acceptance (Sbeglia & Nehm, 2018). The use of simulations and other active learning strategies has been shown to improve these gaps. For instance, using interactive animations of complex geological principles related to plate tectonics can effectively eliminate the differences in science learning between males and females (Sanchez & Wiley, 2010). Others have found that using active learning techniques to teach the intricacies of DNA replication in undergraduate biology classes can have different effects on confidence and retention of material, based on sex (Lax et al., 2017). The use of novel learning tools in the classroom is needed to improve these disparities.

Despite the many hurdles in evolution education and the many differences that exist among students in a classroom, educators have developed tools to help bridge the gap in evolutionary thinking and understanding. Many simulation software programs have been developed in recent years to help students grasp these difficult concepts in a hands-on way. One in particular, known as Avida, was first developed at Caltech in the late 1990s and was further developed as an educational tool, known as Avida-ED, at Michigan State University (Ofria & Wilke, 2004; Pennock, 2007). This program allows students to track asexual self-replicating virtual organisms (known as Avidians) in a virtual environment. Our group and others have found that Avida-ED is very effective in helping undergraduate students gain knowledge about the principles of evolution and natural selection, as well as in increasing the acceptance of evolutionary theory (Speth et al., 2009; Abi Abdallah et al., 2020; Lark et al., 2018). Avida-ED would be most beneficial if it could provide many different types of students from various backgrounds and contexts with a better understanding of the concepts of evolution and natural selection; however, studies to date have not conducted more in-depth assessments of the effectiveness of this program. Given this, we decided to measure how the software affects the understanding of evolution in the various populations of students found in any given classroom. Specifically, we measured student performance, on multiple choice and open-ended questions related to evolution, before Avida-ED instruction began, and we did the same after instruction. From the before and after scores we calculated fold change. The analysis was conducted by grouping the students' scores on the basis of major, sex, class year, and overall performance (final grades) in the course. Overall, we found that the Avida-ED software benefited all groups of students, demonstrating how this digital evolution tool can be helpful to a broad base of students.

○ Materials and Methods

The materials and methods are identical to our first study published in 2020. Here, we provide a brief materials and methods section. Detailed materials and methods can be found in our previous study at the following link: https://doi.org/10.1525/abt.2020.82.2.114.

○ Student Population

The student population comprised undergraduates at Thiel College, a liberal arts college located in Greenville, Pennsylvania. The Avida-ED lab was part of an undergraduate biology course (foundational level, with significantly more freshmen than students in other years) taken by biology and nonbiology majors (to fulfill a core curriculum requirement). $N = 125$ across 10 different sections of the course from five different semesters and taught by six different instructors. Data were collected between 2016 and 2018. The lab component using the Avida-ED platform involved the pre-course instruction of evolutionary principles (students had not been taught evolution in the course before they performed this lab but may have had evolution taught in other courses or in high school).

Avida-ED Software

The Avida-ED software used in this study is available for free from the Michigan State University and can be found here: https://avida-ed.msu.edu/avida-ed-application/.

Avida-ED Experiments and Laboratory Design

Students followed the Avida-ED curriculum that was generated by the design team at Michigan State University. For our study, we implemented the model lessons found in the Avida-ED lab book and curriculum, which can be found here: https://avida-ed.msu.edu/curriculum/. The curriculum focused on the basic principles of natural selection, including variation by random mutations, fitness, functions, and selection, as well as preadaptive versus postadaptive mutations. The exercise titles are described below. We spread the exercises over a two-week period. Students were tested for evolutionary knowledge before introduction of the Avida-ED program with a pretest survey. Subsequently in week 1, we introduced the software, and students ran their first experiment: "Exercise 1: Understanding the Introduction of Genetic Variations by Random Mutation." In week 2, the students ran experiments 2 and 3: "Exercise 2: Exploring Fitness, Functions, and Selection" and "Exercise 3: Exploring Mutations and Selection: Preadaptive or Post-adaptive?" We ended week 2 with a posttest survey (which was identical to the pretest). A timeline of the surveys and Avida lab activities is shown in Figure 1. All Avida-ED exercises were performed and finished before any formal instruction of evolution occurred in the lecture portion of the course.

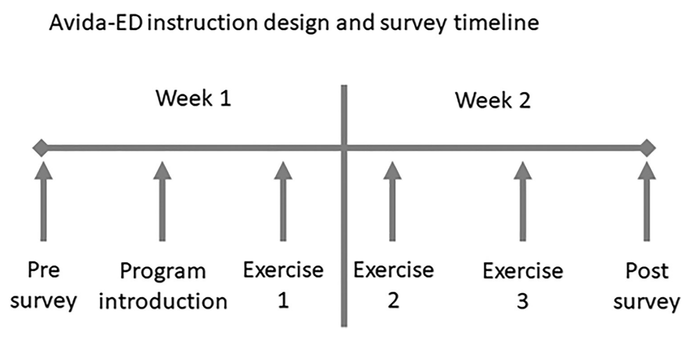

Figure 1. In week 1 of the timeline, students were given a survey to assess their knowledge of evolutionary concepts. The Avida-ED program was introduced and one exercise was performed. In week 2, two more exercises were performed and a post-program survey was conducted to test gains in knowledge and understanding.

Survey (Pre- and Posttest)

The student surveys were conducted at the beginning of week 1 (pretest) and at the end of week 2 (posttest). The survey is based on questions from the Conceptual Inventory of Natural Selection (CINS) (Anderson et al., 2002). The survey was given in the form of hard copies face-to-face with no access to other resources. The students had to complete the survey in class. The students were given the option of whether they wanted to participate in the survey or not (the study was approved by the Institutional Review Board Committee of Thiel College), and several students opted out. Participant compensation was not available.

Survey Analysis, Data Entry, and Statistics

Student answers were graded by professors or teaching assistants. Answers were scored blinded to student names, and a strict rubric was used to ensure reliability between graders. Mann-Whitney *U* and Kruskal-Wallis tests were used to analyze data. Data were analyzed and graphed by using Excel or GraphPad Prism 7.04 (San Diego, California).

○ Results

Student responses to both multiple choice and open-ended questions before and after Avida-ED instruction were analyzed based on various characteristics of the student population (N = 125 students who took the course between 2016 and 2018). First, students were divided into science versus nonscience majors. Science majors included students who were declared biology, chemistry, neuroscience, or physics majors (all possible science majors) when the course was taken (N = 91). Nonscience majors included all math, humanities, and social science students (N = 33). Fold change in correct answers from pre-Avida-ED instruction to post-Avida-ED instruction showed no statistically significant difference. Specifically, the fold change for science majors was 1.453 while the fold change for the nonscience majors was 1.367 (Figure 2, Mann-Whitney *U* test, P = 0.595). Similarly, when the effects of Avida-ED instruction were analyzed based on class year, no statistically significant differences were observed. Freshmen (N = 93), sophomores (N = 5), juniors (N = 6), and seniors (N = 20) had an average fold change of 1.426, 1.507, 1.171, and 1.460, respectively (Figure 3, Kruskal-Wallis test, P = 0.408). Next, the students were divided based on sex. As was seen with major and class year, Avida-ED instruction was shown to be equally effective in both male and female student populations. The average fold change for males (N = 59) was 1.457 and was 1.406 for females (N = 59) (Figure 4, Mann-Whitney *U* test, P = 0.796). All of these data suggest that the Avida-ED instruction helps all student populations.

After the effects of Avida-ED instruction were analyzed based on major, class year, and sex, students in the class were divided into groups based on their performance in the course. In this analysis, the fold change was matched with the final grade earned in the course overall. As was seen with the other parameters, the final grade earned in the course did not correlate with the effectiveness of Avida-ED instruction. Students who earned an A (N = 32) had an average fold change of 1.549; B students (N = 32) had an average fold change of 1.237; C students (N = 31) had an average fold change of 1.439; D students (N = 9) had an average fold change of 1.592; and F/W students (N = 20) had an average fold

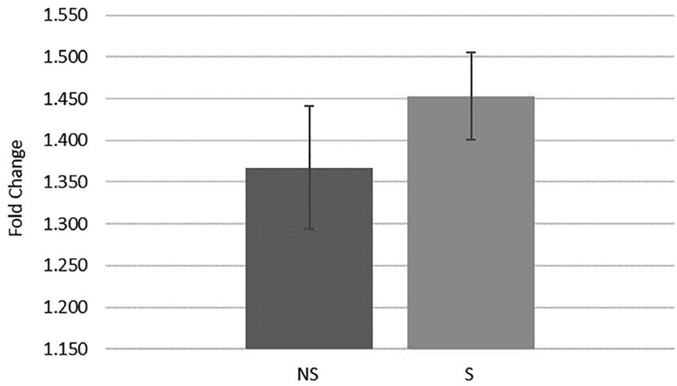

Figure 2. Fold change in pre- and posttest scores for nonscience (NS) and science (S) majors. Nonscience majors had a 1.367-fold improvement while science majors had a 1.453-fold improvement. No statistical difference between nonscience and science majors was observed.

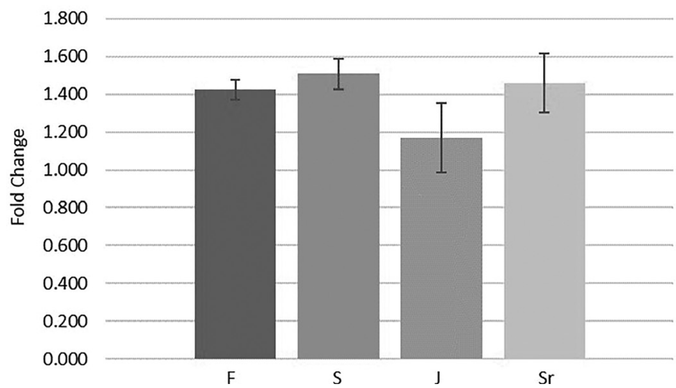

Figure 3. Fold change in pre- and posttest scores for freshmen (F), sophomores (S), juniors (J), and seniors (Sr). Fold change averages: freshmen = 1.426; sophomores = 1.507; juniors = 1.171; and seniors = 1.460. No statistical difference was observed between groups.

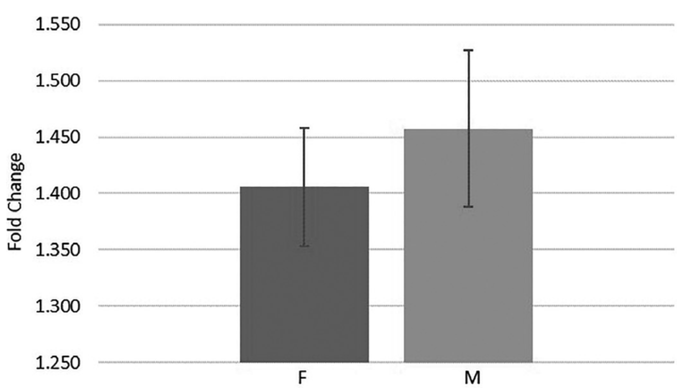

Figure 4. Fold change in pre- and posttest scores for females (F) and males (M). Females had a 1.406-fold improvement compared with a 1.457-fold improvement in males. No statistical difference was observed between the two groups.

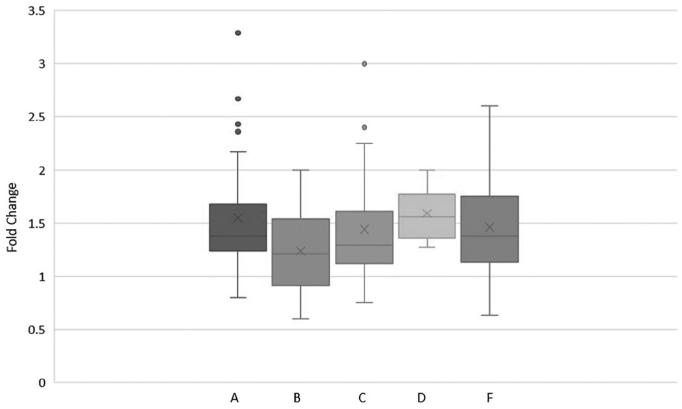

Figure 5. Fold change in pre- and posttest scores according to final course grade. Fold change averages: students earning an A = 1.549; students earning a B = 1.237; students earning a C = 1.439; students earning a D = 1.592; and students earning an F/W = 1.461. No statistical difference was observed between groups.

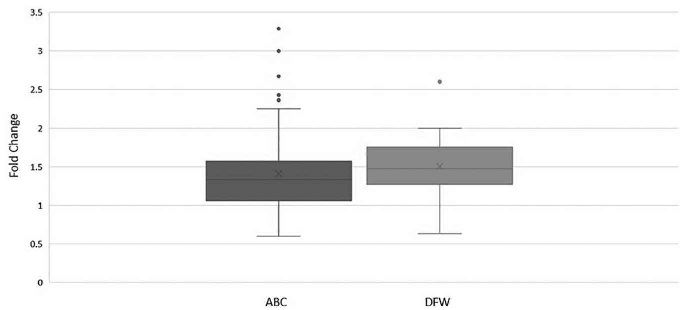

Figure 6. Fold change in pre- and posttest scores according to "passing" and "failing" final course grades. Fold change averages: students earning an A/B/C = 1.408; students earning a D/F/W = 1.501. No statistical difference was observed between groups.

change of 1.461 (Figure 5, Kruskal-Wallis test, $P = 0.659$). For most students, to receive credit for the course, they need to earn an overall grade of at least a C. Therefore, the next analysis combined all of the students who earned an A, B, or C final grade ("passing") and compared them with D, F, or W students ("failing"). As with individual letter grades, no statistically significant differences were found. Students who passed the course ($N = 95$) had an average fold change of 1.408 while students who failed the course ($N = 29$) had an average fold change of 1.501 (Figure 6, Mann-Whitney U test, $P = 0.155$). However, it should be noted that there were some interquartile differences in this analysis. The first quartile value ($Q1$) for "passing" students was 1.057 while for "failing" students it was 1.27. The third quartile value ($Q3$) for "passing" students was 1.57 while for "failing" students it was 1.75. Thus, the interquartile range ($Q3 – Q1$) for the "passing" students was 0.5135 while it was 0.48 for the "failing" students. This may indicate that "failing" students actually benefit more from the Avida-ED instruction than "passing" students, who would have been expected to do well regardless.

○ Discussion

The development of the Avida-ED software allows for numerous possibilities in assessing the performance and understanding of students in regard to evolutionary concepts. Our previous study (Abi Abdallah et al., 2020) showed that the use of Avida-ED technology significantly enhanced the understanding and retention of complex evolutionary principles in introductory biology students. In order to further examine specific differences in this student population in this regard, we used pre- and posttests to analyze potential changes in understanding based on several factors, including major, undergraduate level/year, sex, and final end-of-course grade. Our results demonstrated that there were no significant differences in pre- to posttest fold changes in student performance for any of these factors. Overall, these results indicate that, regardless of major, undergraduate level, sex, or final end-of-course grade, students exhibited similar degrees of improvement in evolutionary understanding, thus supporting the idea that Avida-ED can be used to enhance evolutionary knowledge in all student populations.

Several studies have demonstrated the effectiveness of Avida-ED in enhancing evolutionary knowledge in both high school and college-level students (Smith et al., 2016; Lark et al., 2018; Abi Abdallah et al., 2020). Additionally, changes in student understanding and retention of a variety of evolutionary concepts (genetic variation, carrying capacity, biotic potential, heritability of genetic variation, and origin of species, among other factors) through use of this software can be assessed with the use of the pre- and posttest questionnaires (based on the Conceptual Inventory of Natural Selection; Anderson et al., 2002). In order to further assess the applicability of Avida-ED, we conducted more in-depth analyses of the data from an introductory undergraduate biology course according to sex (male vs. female), undergraduate level/year (freshman, sophomore, junior, and senior years), major (science vs. nonscience majors), and end-of-course grades, and we observed no significant differences in improvement of evolutionary knowledge within these factors. These results demonstrate that, regardless of the type of student and different student populations, Avida-ED can similarly enhance the retention and understanding of complex evolutionary knowledge. In addition to the results of our previous study (Abi Abdallah et al., 2020), the results of the current study further highlight the effectiveness of Avida-ED in advancing evolutionary knowledge in various student populations. This represents a significant advantage of the Avida-ED software in providing an innovative, hands-on, straightforward method for teaching evolutionary concepts in multiple different settings and groups, whether in educational environments or potentially in larger venues, such as scientific community outreach events.

With respect to the final course grade analyses, it should be noted that there were interquartile differences when the A/B/C group data were compared with the D/F/W group data. Specifically, both the Q1 and Q3 values for the D/F/W students were greater than those of the A/B/C students, thus indicating that there was a trend for D/F/W students to exhibit a greater increase in knowledge than the A/B/C students did. This result indicates a possible added benefit of this program, that is, the weaker/at-risk students may be the ones to gain the most knowledge regarding complex scientific concepts, such as evolutionary theory. Moreover, this further supports the use of Avida-ED as a potential active learning tool or strategy that can help struggling students to better comprehend and/or retain information. Various factors can indicate whether a student will struggle with a specific course and be deemed "at-risk," including (but not limited to) student engagement (Ayala & Manzano, 2018; Christenson, 2009) and previous high school educational experiences (Bulger & Watson, 2006; Cyrenne & Chan, 2012; Ficano, 2012). Avida-ED may represent an effective instructional tool that can be specifically used for such at-risk students to better engage them and improve their academic performance, in addition to aiding better-performing students to succeed. Future studies are required to further elucidate whether significant improvement can be observed in poorer-performing students with the use of Avida-ED.

Another potential benefit that may be indicated by our current results concerns the use of Avida-ED to enhance the acceptance of evolutionary theory in different groups of individuals. Although our current experiment did not assess changes in the acceptance of evolutionary theory among students with varying biblical and political views or educational statuses, prior studies have identified these as factors associated with the rejection of evolutionary theory by a high number of adults in the United States (Miller et al., 2006; Hokayem & BouJaoude, 2008; Plutzer & Berkman, 2008; Nelson, 2012; Newport, 2012; Pobiner, 2016). Additionally, previous studies examining the relationship between evolutionary knowledge/understanding and acceptance have yielded conflicting results (Rice et al., 2011; Akyol et al., 2012; Nehm & Schonfeld, 2007; Lark et al., 2018). Clearly, more research and strategies for applying instruction techniques to enhance both evolutionary understanding and acceptance are needed. Based on our results, Avida-ED has great potential in being utilized in a variety of different contexts and settings, such as in lower grade levels, community science outreach events, and a great number of high school and undergraduate institutions. It is possible that if Avida-ED is utilized in multiple different groups to instruct evolutionary concepts in a straightforward, yet interesting and applicable, manner, more individuals will begin to accept the theory of evolution as being valid. Future studies should examine the degree of acceptance of evolution as a result of Avida-ED use in various contexts with parameters similar to those used in this study.

An additional application of the Avida-ED software pertains to its use in online learning environments. Due to the outbreak of the novel coronavirus and the resulting pandemic and school closures, online learning strategies have become vital for numerous courses, especially courses with laboratory components. Moreover, due to the uncertainty regarding school reopenings and the future use of online/hybrid learning for "at-home" students, it is important to consider innovative and simple-to-use strategies for teaching these students. Avida-ED represents an efficient and easily applicable learning tool for teaching a complex subject like evolution in an online "laboratory" setting, with the application of Avida-ED in a digital curriculum having already been demonstrated in a previous study (Smith et al., 2016). Based on these reasons and on our current results, a set of digital laboratory experiments (or even an entire evolution curriculum) can potentially be designed and utilized by virtual-only students in the future.

Similar to our previous study (Abi Abdallah et al., 2020), several limitations were present in the current study. First, both sets of questions in our pretest and posttest (the multiple choice and open-ended questions) only focused on basic, general evolutionary principles. In order to more accurately assess the breadth of knowledge of students concerning evolutionary theory, both "concept knowledge" (e.g., knowledge of a specific evolutionary term or idea) and "process knowledge" (e.g., knowledge about how an evolutionary action or mechanism is elicited) should be analyzed with more in-depth techniques. Additionally, both pre- and posttest questionnaires were identical in terms of the makeup of questions, which may have sensitized students to the assessed concepts, thus resulting in the "practice" effect and increased response rates in the posttest. Moreover, the fact that this course is an introductory biology course means that a significant majority of the students are freshmen, which limits the sample size available to examine how effective Avida-ED is on upper-level students. Indeed, our sample sizes for sophomores and juniors were 5 and 6, respectively. This limits the extent to which our conclusions can be applied to all academic years. Another limitation is the lack of comparison to other instructional strategies. Our study focused exclusively on the use of Avida-ED as an instructional tool, but it is possible that greater learning gains would have been achieved by other means. Finally, as has been previously described, our assessments did not examine the degree of acceptance of evolutionary theory. Future studies should utilize multiple different assessment techniques to analyze various degrees of evolutionary knowledge that may be gained through the use of Avida-ED, and they should focus on different factors, including the acceptance of evolution as a scientific theory, in order to gain a more comprehensive understanding of the benefits of this software.

In conclusion, our results clearly demonstrate that Avida-ED can be applicable and beneficial for a wide variety of undergraduate students, regardless of factors such as sex, educational level, or specific major. These results encourage the continued use of Avida-ED for instructing and enhancing evolutionary knowledge for different populations. Its use may help alleviate issues concerning the rejection of evolution as a scientifically sound theory throughout the United States. Future studies that fully address the impact of this software on the enhancement of evolutionary knowledge and acceptance may predict that use of Avida-ED can have far-reaching implications in both educational and community settings.

References

Abi Abdallah, D. S., Fonner, C. W., Lax, N. C., Babeji, M. R., & Palé, F. A. (2020). Evaluating the use of Avida-ED digital organisms to teach evolution & natural selection. *American Biology Teacher, 82*, 114–119.

Akyol, G., Tekkaya, C., Sungur, S., & Traynor, A. (2012). Modeling the interrelationships among pre-service science teachers' understanding and acceptance of evolution, their views on nature of science and self-efficacy beliefs regarding teaching evolution. *Journal of Science Teacher Education*, *23*(8), 937–957.

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and evaluation of the conceptual inventory of natural selection. *Journal of Research in Science Teaching*, *39*, 952–978.

Ayala, J. C., & Manzano, G. (2018). Academic performance of first-year university students: The influence of resilience and engagement. *Higher Education Research & Development, 37*(7), 1321–1335.

Barnes, M. E., Evans, E. M., Hazel, A., Brownell, S. E., & Nesse, R. M. (2017). Teleological reasoning, not acceptance of evolution, impacts students' ability to learn natural selection. *Evolution: Education and Outreach*, *10*(1), 1–12.

Bulger, S., & Watson, D. (2006). Broadening the definition of at-risk students. *Community College Enterprise*, *12*(2), 23–32.

Christenson, S. (2009). The relevance of engagement for students at-risk of educational failure: Findings and lessons from Check & Connect research. In J. Morton (Ed.), *Engaging young people in learning: Why does it matter and what can we do? Conference proceedings* (pp. 36–84). NZCER Press.

Cyrenne, P., & Chan, A. (2012). High school grades and university performance: A case study. *Economics of Education Review*, *31*, 524–542.

Dunk, R. D. P., Petto, A. J., Wiles, J. R., & Campbell, B. C. (2017). A multifactorial analysis of acceptance of evolution. *Evolution: Education and Outreach*, *10*. https://doi.org/10.1186/s12052-017-0068-0

Federer, M., Nehm, R., & Pearl, D. (2016). Examining gender differences in written assessment tasks in biology: A case study of evolutionary explanations. *CBE: Life Sciences Education, 15*(1). https://doi.org/10.1187/cbe.14-01-0018

Ficano, C. C. (2012). Peer effects in college academic outcomes: Gender matters! *Economics of Education Review*, *31*, 1102–1115.

Green, K., & Delgado, C. (2021). Crossing cultural borders: Results of an intervention on community college biology students' understanding and acceptance of evolution. *International Journal of Science Education, 43*(4), 469–496.

Halpern, D. F., Benbow, C. P., Geary, D. C., Gur, R. C., Hyde, J. S., & Gernsbacher, M. A. (2007). The science of sex differences in science and mathematics. *Psychological Science in the Public Interest, 8*, 1–51.

Hokayem, H., & BouJaoude, S. (2008). College students' perceptions of the theory of evolution. *Journal of Research in Science Teaching*, *45*(4), 395–419.

Johnson, W. R., & Lark, A. (2018). Evolution in action in the classroom: Engaging students in science practices to investigate and explain evolution by natural selection. *American Biology Teacher, 80*, 92–99.

Lark, A., Richmond, G., Mead, L. S., Smith, J. J., & Pennock, R. T. (2018). Exploring the relationship between experiences with digital evolution and students' scientific understanding and acceptance of evolution. *American Biology Teacher, 80*(2), 74–86.

Lax, N., Morris, J., & Kolber, B. J. (2017). A partial flip classroom exercise in a large introductory general biology course increases performance at multiple levels. *Journal of Biological Education, 51*, 412–426.

Miller, J. D., Scott, E. C., & Okamoto, S. (2006). Public acceptance of evolution. *Science*, *313*(5788), 765–766.

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

Nelson, C. E. (2012). Why don't undergraduates really "get" evolution? What can faculty do? In K. S. Rosengren, S. K. Brem, E. M. Evans, & G. M. Sinatra (Eds.), *Evolution Challenges: Integrating Research and Practice in Teaching and Learning about Evolution* (pp. 311–347). Oxford University Press.

Newport, F. (2012, June 1). *In US, 46% hold creationist view of human origins*: Gallup Politics. http://www.gallup.com/poll/155003/hold-creationist-view-human-origins.aspx

Ofria, C., & Wilke, C. O. (2004). Avida: A software platform for research in computational evolutionary biology. *Artificial Life, 10*, 191–229.

Partin, M. L., Underwood, E. M., & Worch, E. A. (2013). Factors related to college students' understanding of the nature of science: Comparison of science majors and nonscience majors. *Journal of College Science Teaching, 42*, 89–99.

Pennock, R. T. (2007). Learning evolution and the nature of science using evolutionary computing and artificial life. *McGill Journal of Education, 42*, 211–224.

Plutzer, E., & Berkman, M. (2008). Trends: Evolution, creationism, and the teaching of human origins in schools. *Public Opinion Quarterly*, *72*(3), 540–553.

Pobiner, B. (2016). Accepting, understanding, teaching, and learning (human) evolution: Obstacles and opportunities. *American Journal of Physical Anthropology, 159*, 232–274.

Rice, J. W., Olson, J. K., & Colbert, J. T. (2011). University evolution education: The effect of evolution instruction on biology majors' content knowledge, attitude toward evolution, and theistic position. *Evolution: Education and Outreach*, *4*(1), 137–144.

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

Sanchez, C. A., & Wiley, J. (2010). Sex differences in science learning: Closing the gap through animations. *Learning and Individual Differences, 20*, 271–275.

Sbeglia, G. C., & Nehm, R. H. (2018). Measuring evolution acceptance using the GAENE: Influences of gender, race, degree-plan, and instruction. *Evolution: Education and Outreach, 11*. https://doi.org/10.1186/s12052-018-0091-9

Siciliano-Martina, S., & Martina, J. P. (2020). Shifting barriers to the acceptance of evolution in an underrepresented student group. *International Journal of Science Education, 42*(13), 2205–2223.

Smith, J. J., Johnson, W. R., Lark, A. M., Mead, L. S., Wiser, M. J., & Pennock, R. T. (2016). An Avida-ED digital evolution curriculum for undergraduate biology. *Evolution: Education and Outreach*, *9*(1), 1–11.

Speth, E. B., Long, T. M., Pennock R. T., & Ebert-May, D. (2009). Using Avida-ED for teaching and learning about evolution in undergraduate introductory biology courses. *Evolution: Education and Outreach, 2*, 415–428.

Stover, S. K., & Mabry, M. L. (2007). Influences of teleological and Lamarckian thinking on student understanding of natural selection. *Bioscene: Journal of College Biology Teaching, 33*, 11–18.

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