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Archaeopteryx Fossil: A Paleontological Puzzle Activity to Engage Undergraduate Science Majors

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Abstract: Developing strategies for teaching undergraduate science majors about evolution and the earth's history presents student comprehension and engagement challenges. Pedagogical methods outside the typical Socratic lecture method are needed to allow students to develop a scientific and collaborative mindset that fosters taxonomic and geological concepts fundamental to understanding evolution. We created an inquiry activity to encourage group learning alongside promoting discovery and thinking like a scientist, which involved sequentially revealing only portions of an *Archaeopteryx* fossil in sections. The mystery taxa or puzzle activity was given to first-year college students. We quantified the activity using a combination of a worksheet for taxa and a post-activity survey gauging student perceptions of this activity using descriptive statistics and a Chi-Squared analysis. Student feedback on the activity as engaging was overwhelmingly positive (98.6%), with the majority of students reporting their increased understanding of the process of science for identification of fossils $X^2(1,n = 140) = 59.961$, $p < 0.001$, and as a fun, informative method for learning about fossils, $X^2(1,n =$

140) = 60.682, $p < 0.001$. By the end of the activity, most students could identify the *Archaeopteryx* fossil as a bird based on responses, particularly when the complete fossil was uncovered. This fossil puzzle activity can easily be modified to be used at any academic level (e.g., K-12, pre-K, university) to engage future scientists using alternative fossil specimens with specific morphological traits or incorporated into learning modules focusing on evolution, zoology, anatomy, or paleontology.

Keywords: science education, higher education, STEM education, fossils, paleontology

Introduction

For many first-year college science students, developing a fundamental understanding of evolution and the history of life is vital for scaffolding future critical concepts in biology. However, there is a need to create more hands-on activities outside of standard Socratic lecture methods when introducing the rich diversity of biological life across geological time scales and evolutionary change using the evidence of fossils. Fossil casts are an effective tool for teaching students about human primate origins when skulls are utilized, enabling students to learn about human evolution (Gipps, 1991), and more recently with 3-D printed human skull replicas (Diaz-Navarro & Parra-Perez, 2023). However, more work remains to be conducted outside of many human anatomy and physiology models and specimens used in courses, bridging the gap across sciences for including fossils as a teaching pedagogy. Exposing biology majors to a broader understanding of evolution using non-human fossils of other vertebrates is vital to increase perspective on evolution as a unifying biological principle utilizing the light of evolution approach (Dobzhansky, 1973). Therefore, incorporating fossils and the process of fossilization in the classroom holds much promise as an educational tool across academic levels.

While some science majors may find fossils fascinating, it may be difficult to “bring them to life” or allow students to envision fossils as more than preserved fragments of organisms, especially if they are presented as images in lecture or a 2-D format. Educators can use biological collections to increase students' understanding of key evolutionary concepts in the classroom (Kreuzer & Dreesmann, 2017). Inquiry-based activities using reconstructed fossil models alongside animal specimens and skeletons emphasizing specific anatomical structures as an interesting informal science educational tool can aid in the retention of critical biological ideas (Nesimyan-Agadi & Assaraf, 2022) as well as highlight the role of fossils in determining past environments and ecological habitats (Angseesing, 1979). Incorporating fossils into teaching biology may provide not only evidence of prehistoric life, but many students find fossils interesting and fun to examine (Dilcher, 1967) while also teaching the important concept of natural selection to undergraduates using examples from the fossil record (Dodick & Orion, 2003). While undergraduates need to learn about evolution and the importance of fossils, which provide evidence for evolution, there are very few activities in the published literature emphasizing transitional fossil education for biology or science majors.

Therefore, using fossils in the classroom may concomitantly teach evolution to biology majors and non-majors and allow students to develop critical communication, collaborative, and cognitive skills. This style of short activity may further develop important knowledge and application of skills across the science curriculum, whereby students engage in learning and may be driven to learn in hands-on activities.

Research Problem

Standard methods for lectures in biology and science classrooms present challenges for student engagement, particularly when it is essential for students to learn new information related to the evolution of specific groups of organisms and also to develop an understanding of the importance of scientific discovery more fully. Content-heavy courses in the biological sciences are often designed to focus on fundamental knowledge and would greatly benefit from incorporating alternative teaching strategies. There are problems in tradeoffs between covering content versus incorporating teaching pedagogies that engage students in science. There seems to be a deficit in incorporating collaborative development of critical thinking skills in introductory coursework in organismal biology, which engages undergraduates. Moreover, the understanding of evolution among college graduates is often lacking (Alters & Nelson, 2002), with students struggling to understand evolution, even given its importance to an undergraduate biology education (Hsu et al., 2024). Part of this problem in teaching and learning may stem from the instructional setting, as the topics of natural selection and evolution are challenging to observe in the laboratory or lecture hall (Abdallah et al., 2023). In addition, undergraduate and even graduate biology students can struggle with the zoological classification of organisms and overall taxonomy (Kaushik & Kachhwaha, 2024). Educators can sometimes impact This gap in students' education, which, if exposed to specific coursework on evolution and science, can help prepare educators on proper methods for teaching evolutionary examples at the high school level (Branch et al., 2023). Therefore, this paper provides an example of how science educators can overcome some of the challenges in biology and the teaching of evolution by allowing students to problem-solve, work in groups collaboratively when gaining new knowledge, and engage in science when learning about important fossils in hands-on learning activities.

Research Focus

This study focused on the role of brief group work activities in imparting knowledge on evolution and biology and promoting higher learning through student examination of sequential portions of a puzzle or mystery fossil. It sought to implement and assess whether this activity was engaging and allowed students to gain critical thinking skills working collaboratively in a science course.

Research Aim and Research Questions

This activity aimed to develop a new teaching pedagogy of interest for students to engage and learn to develop critical thinking skills in a lecture environment. Herein, we used a hands-on mystery puzzle fossil approach in an introductory biology lecture group activity to foster discovery and inquiry when teaching about fossils and the earth's history and evolution. We assessed whether this teaching pedagogy was engaging to students overall. Specifically, we evaluated if it was 1) informative, 2) allowed students to learn about how science works, and 3) lastly, how working in groups enabled students to solve the problem of a mystery fossil under a scenario where they were "paleontologists."

Literature Review

Previous work using fossil activities to teach evolution includes using engaging sequential paper handouts to teach about fossils for students for early flying reptiles, *Scaphognathus*, and early whales, *Pakicetus*, as a methodology to allow continuous discovery in the classroom (Slesnick et al., 1985). This approach provides for teaching students that ideas change as new evidence is revealed based on new data or information. With an emerging emphasis on STEM (science, technology, engineering, and mathematics) education, the inclusion of fossils in learning can allow students to carefully examine morphological adaptations in vertebrates and gain a deeper understanding of the scientific process and importance of paleontology to biology (Redman et al., 2021). An active learning activity may allow for a new understanding of geoscience and paleontological concepts (Dahl, 2018). Problem-based learning thrives as a pedagogy in Paleontology courses (Montgomery & Donaldson, 2014). Moreover, utilizing collaborative learning methods (students working in small groups) can allow students to develop critical thinking skills alongside engaging them at higher levels of active learning (Hager et al., 2003;

Hodges et al., 2018). Collaborative learning can also improve learning for biology topics that do not easily lend themselves to specific laboratory experimental activities (Baken et al., 2022).

Methods for engaging students in the biological sciences can include developing course-based undergraduate research experiences, or CUREs, which may allow students to learn problem-solving skills alongside critical thinking skills (Appel et al., 2024). Alternative methods for exposing undergraduate involvement in biodiversity science include developing programs involving students as part of museum collections (Hiller et al., 2017). However, not all educators can provide such time-intensive forms of learning for all students within the undergraduate college experience or have access to resources such as museum collections.

While there is a dearth of published studies using similar approaches as a teaching framework, in science, collaborative problem-solving is a standard method in mathematics and science (Hoffman & Mercer, 2016). Moreover, it is often a tradeoff for many teachers how much time to spend on classroom time for group work over imparting information in content-heavy science courses, particularly in first-year university biology classes. Therefore, developing activities that outline how simple lesson plans may promote collaboration and student-centered learning is essential, as there is little information on using fossils in the biology college curriculum. It is also possible that, given the resources available, many universities worldwide may not have access to fossil collections or the ability to explore local field sites or hold classes in museums with adequate time. To this end, we implemented the present activity and characterized student perceptions of learning in a collaborative, scientific classroom atmosphere where groups took on the role of fossil discovery.

Materials and Methods

Sample and Participants

This activity was deployed in a first-year biology course at a small liberal arts university and approved by the Wingate University Research Review Board (protocol #SU090122). Student participants were enrolled as first-year students, and this activity was implemented as part of a standard lecture class. Sample participants included biology majors enrolled in an introductory "Principles of Ecological and Evolutionary Biology" course. They agreed to have their data collected during surveys as part of this activity. In our sample, we included all students who attended class for a total sample size of 140. Student participant data was entered into Excel and randomized for order of data entry (taxonomic choices decided by groups for each puzzle piece revealed) and for individual responses to survey questions. All student participation was included, and representative feedback comments were selected from data entered from surveys. We included student data from a Spring and Fall semester course in 2024 to have the highest sample size for this activity. Following a module on geology and fossils and their importance to biology as a short primer, students were divided into groups of three to four and worked together during class to complete the worksheet activity and the survey, which immediately followed the in-class activity.

Procedure

Each group was given an envelope and presented with an activity scenario (presented via PowerPoint). The scenario involved paleontologists digging at a fossil site and slowly uncovering a new fossil discovery. Students were asked to open the envelope and take out the first square labeled '1' (lower right corner of fossil cutout), corresponding to ¼ of the scanned fossil printout. They were then given ~3-5 minutes to observe the fossil and provide a best guess as to what kind of animal the fossil was based on any visual morphologies as clues. Then, they were instructed to take out the second square labeled '2' (upper right of fossil cutout) and given ~3-5 more minutes to piece together and observe.

Following the exact procedure, they took out the third square labeled ‘3’ (lower left of fossil cutout). Finally, they were instructed to remove the last square labeled ‘4’ (upper left of fossil cutout) from the envelope, piece together, and observe and analyze the completed fossil in another ~3-5 minutes. The sequence of squares revealed was selected to highlight particular features of the fossil. In summary, for each puzzle piece of the *Archaeopteryx* revealed, the students worked together to determine what kind of organism the fossil represented and filled out two questions in the worksheet for each puzzle piece revealed, consisting of “*What do you think this fossil is and why*?” and also “*What traits are present?*”.

During each activity step, instructors (authors) went around the classroom. They asked a representative from each group to “report” on what kind of organism the fossil was and why or what morphological features they used to arrive at their decision. By the end of the activity, groups had the complete Berlin specimen of *Archaeopteryx lithographica* available to examine, clearly showing soft wing tissue, teeth, long bony tail, claws, and furcula. The complete fossil was also projected on the screen after all groups had reported what type of animal the mystery fossil was and introduced as *Archaeopteryx*, an essential transitional fossil from ~150 million years of age, with traits of both birds and dinosaurs. Instructors went over the specimen, emphasizing important morphological characteristics. Immediately following the activity, instructors showed a replica fossil of the type specimen so students could see the 3-D replica to understand the morphological traits of this transitional fossil (i.e., presence of claws, teeth, soft impression of wings, and furcula). Students then completed the survey, and a class discussion about the nature of science, which *Archaeopteryx* features stood out the most, why science works on the information at hand, and whether everyone at all stages of the activity agreed on the fossil taxa identification.

Worksheet

The authors manually entered data from the in-class worksheet. Possible taxonomic organisms were entered for each puzzle piece, allowing for multiple entries per puzzle piece, one, two, etc., up to four total (complete puzzle visible). This was necessary if groups either couldn’t agree on one form of taxa that the fossil represented or if they thought it was possibly multiple taxa. A response from a frog was categorized as “amphibian,” and any response from a turtle or lizard was classified as “reptile.” Similarly, any bat response was categorized as “mammal,” and a response of either fish or stingray was reported as “fish.” These broad categories were utilized to simplify this activity's reporting of broad taxonomic groups. In short, if students mentioned organisms may have been either a “bird” or “reptile,” then both bird and reptile were entered as options.

Post-Activity Survey

Data was manually compiled from an anonymous post-activity Likert scale questionnaire. This survey consisted of four total questions. The first question, A) asked, “Was this activity an engaging way to learn about an important transitional fossil?” with the possible response of either “Yes” or “No.” The second and third questions, B) and C), consisted of Likert scale questions and asked, “ On a scale of 1 to 6, did the *Archaeopteryx* activity help you learn about how science works in steps, especially concerning the identification of fossils?” and On a scale of 1 to 6, was the *Archaeopteryx* activity a fun and informative way to learn about fossils?”, respectively. The Likert scale was as follows: 1 = “Strongly Disagree”, 2 = “Disagree”, 3 = “Slightly Disagree”, 4 = “Slightly Agree”, 5 = “Agree”, 6 = “Strongly Agree”. The final question, D) consisted of an open-ended question prompting additional comments on the *Archaeopteryx* activity, where students were encouraged to write at least two to three sentences of feedback on the overall activity.

Data Analysis

We mainly report descriptive statistics on this activity derived primarily from the post-activity survey and taxonomic categories for the mystery organism from the worksheet and data entered into Excel software. Moreover, we qualitatively selected representative comments or responses to survey question D for feedback on the activity overall. We did quantify specific numerical data results from the post-activity survey questions. We compared survey questions B and C responses using a Chi-Squared Goodness of Fit analysis in R version 4.1.0. For both tests, we used 0.05 as our level of significance.

Results

We present results for a total of 140 student participants. Responses to survey question A were 98.6% Yes and 1.4% No. Responses to Survey Question B were largely positive, with students mostly agreeing and strongly agreeing that this activity helped them learn about how science works in steps to identify fossils. We found significance when analyzing responses to question B, $X^2(1, n = 140) = 59.961$, $p < 0.001$. Similarly, responses to survey question C were also mostly agreeing or strongly agreeing that this activity was a fun and informative way to learn about fossils. We found significance when analyzing responses for question C, $X^2(1, n=140)= 60.682$, $p < 0.001$.

Across the activity for all pieces revealed, groups selected “bird” (79) as the most frequent response for the possible taxonomic category of the mystery fossil, followed by “animal” (34), “reptile” (25), then “dinosaur” (16), “pterodactyl” (15), “fish” (8), “amphibian” (6) and “mammal” (6) (Figure 2), indicating a range of responses, some of which changed as more puzzle pieces were utilized. Moreover, by the end of the activity, when all four squares were showing the entirety of the fossil, the majority of groups (92%) wrote down either “bird,” “pterodactyl,” “dinosaur,” or “reptile” for their taxonomic category. Several groups did not agree at various stages of the activity. Still, most reported that group discussions led to some agreement on what the possible fossil could represent when they filled out the worksheet for each puzzle piece (1 to 4).

Representative student participant feedback from the activity within the classroom on science as a process included “*results may vary with new evidence*,” “*to educate more on the study of life*,” “*a hypothesis may be different as new information comes to light*,” “*it is important to reassess to see the whole picture, not just pieces*” and “*you can learn new things as new information is found*” or “*as new information becomes available, old opinions are subject to change*” and “*sometimes you need discoveries to make things more clear in science*,” “*new data can create new questions*.” Additional comments on group learning included “*Different people bring different points of view*,” “*While we didn’t always agree on what the mystery fossil was, we were respectful and discussed various ideas in our group,*” and “*why it is important to think like a scientist and put pieces together as they come into the light*.” Therefore, when taken together, feedback from student participants was somewhat varied but overwhelmingly positive and qualitatively matched responses to questions A, B, and C.

Table 1

Results of Post-Activity Survey to question A (“Was activity engaging?”), Likert questions B (“Did activity help you learn about how science works when identifying fossils?”) and C (“Was activity fun and informative?”), with representative responses to Additional Comments or Question D (“Additional comments on activity, interesting things learned from activity, and important traits used to identify mystery fossil”)

Survey Question	Responses

A	98.6% YES; 1.4% No
B	Median = 5; Min = 3, Max = 6
C	Median = 6, Min = 3, Max = 6
D	Representative Responses = “*It was interesting that an animal could have characteristic traits of another animal,*” “*The most interesting thing was putting the fossil pieces together but seeing something different each time,*” “*I think the most interesting thing I learned is that other people’s opinions may change your idea of what it is if they don’t agree,*” “*This was an actual fun activity and allowed us to interact with classmates*” “*It was super interesting that as more was revealed, the more my group’s answer changed*” “*I learned how paleontologists may think and change their thinking based on new data*” “*it was a great activity which allowed our group to use prior knowledge to try and guess that fossil it was*” “*We loved building the puzzle.*”

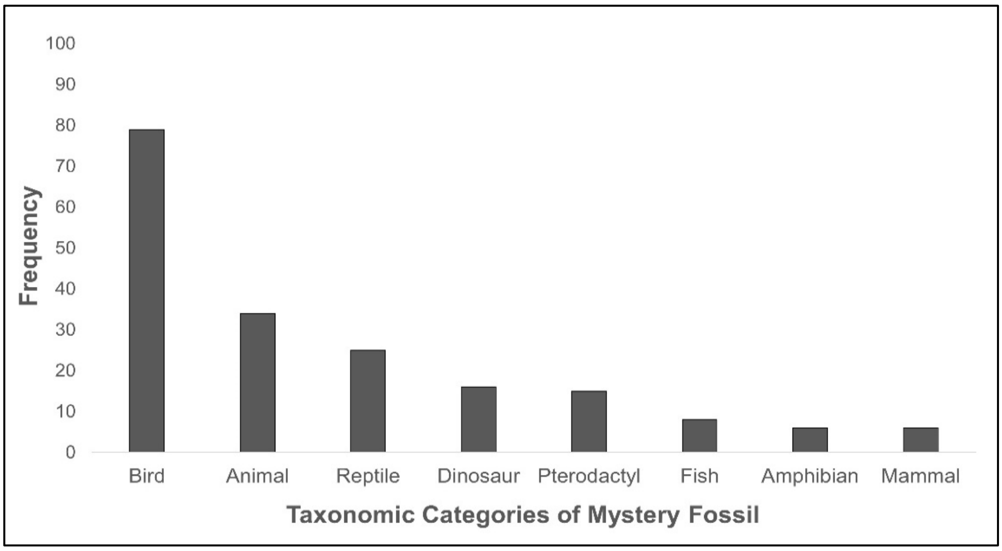
Source: Based on survey results.

Figure 1

Example of the printed copy of Archaeopteryx fossil with all four pieces. Pieces revealed in the following order: #1 (Lower Right), #2 (Upper Right), #3 (Lower Left), #4 (Upper Left)

Figure 2

A Relative Frequency of Taxonomic Categories Filled out by Students During this Activity, Representing all Four Puzzle Pieces



Note. Multiple categories may have been selected for each puzzle piece.

Source: based on survey results.

Discussion

We found this short activity engaged undergraduate biology majors and fostered group work while concomitantly teaching students to "think like a scientist" and to use data available at any one time to infer organisms as a fossil discovery. Emphasizing evolution and the nature of scientific inquiry alongside uncertainties taxonomically that accompany science may lead to a greater student understanding of biology and science in general (Nickels et al., 1996). This also promotes problem-based paleontology as a tool for students to develop critical thinking and problem-solving abilities (Cox et al., 2019), a component of "thinking like a scientist." Moreover, our activity promoted active learning and a focus on science as a process, which can improve students' understanding of evolution (Johnston et al., 2022). We found it surprising that many students did not immediately recognize the fossil specimen, as it is likely among the most well-known fossils. This may be due to introductory, first-year biology majors' varied backgrounds, largely pre-medical majors, or a lack of familiarity with *Archaeopteryx* outside academia. Based on student feedback, students found this brief lecture activity to be an engaging and informative lesson about evolution and transitional fossils.

Increasing student awareness of evolutionary events and transitional fossils goes hand-in-hand with significant concepts taught in first-year introductory biology courses and should therefore be emphasized using activities similar to this instructional method, alongside more hands-on approaches of examining fossils first-hand. While we did show the actual replica fossil towards the end of this activity, further work on developing pedagogical methods for students to engage with fossils should likely include student examination of real fossils. Another important point regarding this activity was that paleontological finds are never "instant" and take time to unravel the complete fossil. It is important to note that the authors did not bias the students' thought processes by giving clues and instead allowed students to work together to solve this puzzle. We observed students working together in groups to help solve the mystery based on specific morphological traits and discuss possibilities for potential organisms, which fostered group learning, a vital pedagogy in undergraduate STEM science (Springer et al., 1999). Moreover, biology majors must engage in scientific practices, especially those that allow for communicating science (Wack et al., 2021) or problem-based project learning in introductory biology classrooms (Webster et al., 2022).

This activity helped to show students that individual organisms are often preserved in various states of arrangement, illustrated by the head of the fossil pointing towards the posterior of the specimen. This may have contributed to the difficulty of identifying specific taxa, given the head was not observed until the end of the activity with the last square of the puzzle. It has been noted that many dinosaurs and birds are preserved in an opisthotonic posture with extreme dorsal neck retraction (Faux & Padian, 2007). However, each square presented to students contains several features that help the student identify a particular taxonomic grouping. With square '1' of the fossil, the student can recognize that the fossil is from a vertebrate with claws/talons without being aware of the specimen's general orientation. With subsequent squares revealed, different traits become observable. Square '2' shows a wing and feather impression with claws visible on the limb. With square '3', a bony tail can be observed surrounded by feather impressions. The last square, '4,' brings the head, long neck, beak with teeth, and another limb and wing. Once the four squares are pieced together, the student can observe the furcula (wishbone) and all four limbs, spread out wings and feathers, and understand the fossil's orientation. This cost-effective activity can easily be modified or substituted with a different fossil specimen to help students understand other historical evolutionary events, e.g., evolution from fish to amphibian, whale evolution, or non-vascular to vascular plant. However, when selecting a fossil to utilize in a sequential puzzle lesson format, it is essential to ensure specific morphological features are present in the specimen or become apparent once the complete fossil is examined, whether an actual or paper cutout is used, similar to this lesson.

Complementary methods to this activity include exposing undergraduate biology majors to real fossils or visiting local paleontological field sites or museums when possible. Field experiences that allow students to build paleontological knowledge are an additional method for teaching about fossils and the science of paleontology (Lepore et al., 2021). However, financial resources, temporal constraints, and availability of access to these field sites may be limited to many educators. Hence, this brief in-class lesson provides a road map for incorporating group learning using an evolutionary significant transitional fossil. Alternatives to standard handouts include utilizing micropaleontology reconstruction using sketches and web-based tools to promote fossil identification skills (Stepanova et al., 2024). Instead of actual fossils, more affordable replicas can be used whereby students can still develop inquiry-based skills and critical thinking using simulated fossils to learn about paleoecology processes (Shroat-Lewis & Hage, 2021). Another complementary method for teaching college undergraduates about fossils involves utilizing board games demonstrating the process of fossilization (Martindale & Weiss, 2020) or natural selection (Martindale et al., 2024). Alternatively, educators can organize an entire hands-on laboratory or lecture utilizing actual fossils, with an emphasis on morphological changes throughout the fossil record (Platt, 1999), or engage students through the use of technology using 3-D reconstruction of fossils via virtual paleontology to promote greater understanding of evolution (Rahman et al., 2012). Moreover, this activity can be modified or with similar fossils using technology to be deployed in a virtual, online lab, as these topics can effectively impart student conceptual understanding (Byukusenge et al., 2022). To specifically reinforce the dinosaur-bird evolution connection using vertebrate anatomy, dissecting chicken wings can also provide an affordable method to allow students to evaluate further the skeletal structures in larger enrollment classrooms (Soja, 2018). We recommend utilizing our activity or modifying this lesson plan alongside other teaching methods, which allow science instructors to create a classroom environment that fosters cooperative and collaborative team learning in an informative and engaging way when learning about fossils that provide evidence for evolution.

Conclusions

First-year undergraduate science majors need to develop problem-solving skills, which they can apply well into their academic and professional careers. To this end, we recommend similar engaging activities be incorporated into standard Socratic lectures, allowing students to work collaboratively in classes where they learn the importance of discovery and develop communication skills while gaining knowledge and skills related to biology. In addition, this provides an opportunity for instructors to provide instant feedback on STEM pedagogies, which likely scaffold to other higher-level courses. It is essential to impart fundamental knowledge in first-year science courses and allow students to engage with the content in a format that may further allow them to learn more, which may translate to higher-level learning in science.

Limitations and Future Research

While student participants rated this activity as engaging and an informative tool for learning about fossils and evolution, there may be certain limitations to this research and application of this activity. The first and foremost includes using a paper cut-out versus a real fossil. However, given the cost of either authentic or replica fossils, this short activity was meant to provide an in-class lecture method that emphasizes the nature of scientific discovery and group work. Moreover, it is unclear if this lesson plan could be applied to other essential biological examples outside evolution and biology. Additionally, we expect possible applications of this puzzle activity to be modified to be potentially online or with puzzles manipulated using software technology, which would be an alternative effective strategy for incorporating technology into this activity. However, if other fossils are used as examples, this approach could represent an effective teaching tool for educators to engage their students in a fun, collaborative environment that imparts the thrill of discovery science. Moreover, any activity that engages and provides an avenue for students to apply their biological knowledge and reflect on their own science identity may increase their confidence (McCartney et al., 2022). In summary, this pedagogical approach could be used in any science classroom where students work together to develop critical thinking skills to solve problems and think like a "scientist" in any STEM field across educational levels.

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Conflict of Interest

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