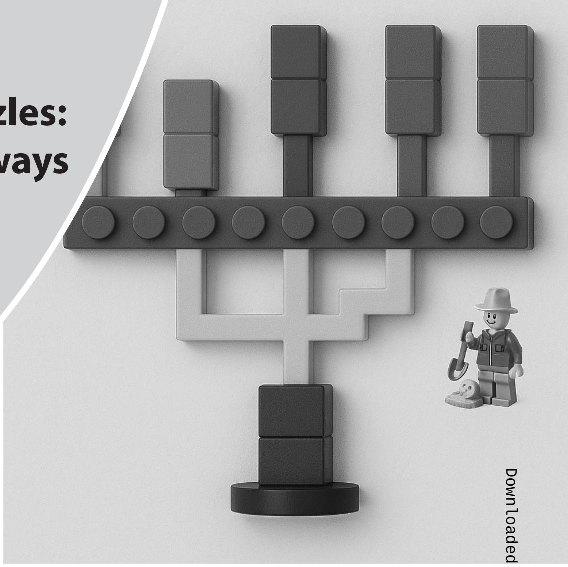
Digging into Phylogenetic Puzzles: Unearthing Evolutionary Pathways with LEGO Bricks



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Abstract

Developing tree-thinking skills is vital for achieving a deep understanding of evolutionary processes, advancing scientific literacy, and strengthening core biological knowledge. This study explores an inquiry-based activity where students use LEGO bricks as model taxa to construct and interpret phylogenetic trees. The activity aims to demonstrate the dynamic nature of evolution, support the development of tree-thinking skills, and highlight the role of cumulative evidence in understanding evolutionary relationships. Implemented with 18 senior-year pre-service biology teachers in an Evolution Theory course, the activity provided an engaging, hands-on approach to exploring evolutionary concepts. This LEGO-based tree-thinking activity successfully promoted scientific reasoning and collaboration, serving as a valuable resource for educators seeking to enhance students' understanding of phylogenetic principles and evolutionary mechanisms.

Key Words: *phylogenetic trees; tree-thinking; evolutionary processes; LEGO.*

○ Introduction

Phylogenetic trees, alternatively known as evolutionary trees, are visual representations illustrating the evolutionary connections between species or populations (Halverson et al., 2011). The term "tree-thinking" encompasses the analytical skills and evolutionary knowledge required to interpret information concerning relationships and evolution within phylogenetic trees (Baum & Smith, 2013; Gibson & Cooper, 2017). In grasping the concept of evolution, the capacity for "tree-thinking" is an essential element in fostering a precise comprehension of the evolutionary process (Baum & Offner, 2008; Meisel, 2010). Enhancing tree-thinking skills also contributes to advancing scientific literacy and deepening the understanding of critical topics such as climate change, health, agriculture, forensic science, and biotechnology (Daniel et al., 2024). It is crucial to educate students on how biologists employ evolutionary trees, aiming to foster a systematic and comprehensive understanding of these trees akin to the perspective of biologists (Brower, 2016; Kong et al., 2022). However, studies indicate that students encounter difficulties in comprehending these trees (Bokor et al., 2014; Catley et al., 2013; Daniel et al., 2024; Halverson et al., 2011; Kong et al., 2016; Meir et al., 2007) and hold numerous widely recognized misconceptions (Gregory, 2008; Schramm & Schmiemann, 2019). Students often misunderstand phylogenetic trees by misinterpreting species' placement along the tips, misjudging relatedness based on proximity or tree shape, and applying alternative conceptions such as ladder thinking, reading only the tips, or associating longer lines with lack of change, while also struggling to adapt to varying tree representation styles (Daniel et al., 2024; McCullough et al., 2020). Those misconceptions and challenges highlight the importance of effective and well-designed tree-based instruction.

To enhance tree-thinking skills, several educational initiatives have been introduced and assessed over the past decade (Kong et al., 2022; Walter et al., 2013). For instance, Gibson and Cooper (2017) created the Botanical Phylo-Card Game, which uses tree-thinking to explore natural groups and highlight key events in the evolutionary history of terrestrial plants. McCullough et al. (2020) introduced a student-focused module designed to enhance tree-thinking skills by utilizing both phenotypic and molecular data to guide students in constructing phylogenetic trees and interpreting the evolutionary relationships they depict.

In addition, it is pointed out in many studies that the use of fictional organisms proves highly advantageous in taxonomy and the interpretation of evolutionary trees, facilitating easy character definition and enabling the utilization of authentic phylogeny as a foundation (Schramm et al., 2022). Moreover, offering simple and visually engaging activities can enhance teachers' confidence and encourage them to present the material (Dorrell, 2019). In this study, we developed an inquiry-based activity in which students construct phylogenetic trees using LEGO bricks as model taxa to engage with the dynamic nature of evolution, develop their tree-thinking skills, and recognize the importance of cumulative evidence in building scientific knowledge. We implemented the activity with senior-year pre-service biology teachers in an Evolution Theory course, but it can be modified in various ways to accommodate students across different educational levels, from elementary to undergraduate studies.

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○ Alignment with NGSS

The activity outlined here enables students to participate in multiple Science and Engineering Practices as defined by the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). Students will specifically engage in developing and using models, analyzing and interpreting data, constructing explanations, and engaging in arguments from evidence. By actively participating in the practices employed by scientists and engineers, they gain a deeper and more meaningful learning experience while understanding the relevance of science, technology, engineering, and mathematics (STEM) in their daily lives (NGSS Lead States, 2013). Furthermore, this module incorporates several NGSS Crosscutting Concepts, such as patterns; cause and effect; and scale, proportion, and quantity, which help students connect knowledge across scientific disciplines, fostering a more cohesive and scientifically grounded perspective on the world (National Research Council, 2012).

This activity is also closely aligned with the NGSS for High School Life Sciences (HS-LS), addressing several key objectives. It supports HS-LS4-1 by encouraging students to communicate scientific evidence demonstrating how common ancestry and biological evolution are backed by multiple lines of empirical data. Additionally, it aligns with HS-LS4-2 by guiding students to construct evidence-based arguments about how changes in physical or biological components of ecosystems impact populations. Through HS-LS4-4, students develop scientific explanations based on evidence to understand how natural selection drives population adaptations. Lastly, it fulfills HS-LS4-5 by prompting students to evaluate evidence regarding the effects of environmental changes, including species population growth, the emergence of new species, and species extinction.

○ The Activity

Preparation of LEGO Brick Taxa for the Activity

To begin, we assembled four trays and labeled them as Tray 1, Tray 2, Tray 3, and Tray 4. We also used LEGO bricks of various colors (green, white, yellow, gray, and blue) and sizes (1×1, 1×2, 1×3, 1×4, 2×2, 2×3, 2×4).

In designing the LEGO brick taxa used in this activity, we began by constructing three major clades—White, Yellow, and Green—to create a fictional phylogeny. First, we created the models in Tray 4, which represents the oldest point in the fictional fossil record—30 million years ago (Figure 1). Starting with three clades approach was intentionally chosen to provide a greater diversity of examples and to encourage students to engage with a wider range of morphological traits. However, to avoid polytomies and promote meaningful tree construction, we made an evolutionary assumption: the White and Yellow clades share a common ancestor, distinguishing them from Clade X. As a result, the phylogenetic tree inferred from Tray 4 will appear to branch into three main lineages. While this structure aids in instructional clarity and tree-building practice, it is important to note that it may suggest an inaccurate evolutionary implication—those three distinct clades emerged directly from a single ancestor without further divergence patterns. Since Tray 4 acts as the starting point for subsequent evolutionary stages, the organisms in this tray should be morphologically simple, constructed using fewer and smaller pieces (e.g., 1×1 and 1×2). These forms represent early or ancestral lineages. The LEGO taxa in each tray represent average individuals from populations of a species distributed across different regions of a fictional world.

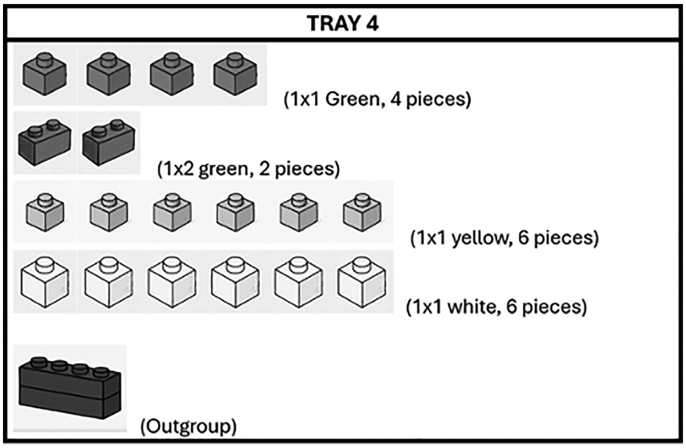

Figure 1. LEGO Bricks in Tray 4.

In our example, Tray 4 contains 20 LEGO brick taxa, along with two additional, morphologically distinct LEGO models used as an outgroup to root the phylogenetic tree.

After completing Tray 4, we proceeded to build the other three trays:

- Tray 3 (20 million years ago)
- Tray 2 (10 million years ago)
- Tray 1 (present day)

This forward-building approach allowed us track trait changes and simulate lineage divergence over time. As we moved from Tray 4 to Tray 1, we modified one or two traits per organism—such as color, size, number of bricks, or their arrangement—to reflect evolutionary change. These changes are upon the instructor's choice. We randomly assigned the letters near the models in Tray 1. Figure 2 illustrates our models in Trays 1 and 3. In addition, Appendix B shows our strategies to develop LEGO brick taxa in our fictional earth.

In our example, Tray 3 includes 18 models, Tray 2 includes 27 models, and Tray 1 includes 38 models. Some models may remain unchanged across trays to illustrate evolutionary stasis, while others may disappear, reflecting extinction or gaps in the fossil record.

Once all organism examples are created, they are placed into the appropriate trays. The trays are then stacked in sequence, with Tray 4 at the bottom and Tray 1 on top, preparing the full model for student interaction. This completes the preparation of the model for the activity. These trays will be presented to students in a sequential order. The purpose of organizing the trays in this way is to offer a visual and comparative model of evolutionary change. Variation in LEGO brick color, size, and arrangement is used to simulate the diversity of heritable traits in living organisms, making it easier for students to observe evolutionary patterns. Instructors may choose to customize LEGO taxa depending on instructional goals, allowing flexibility in trait design and organism modeling. Although the full activity uses four trays, it can be simplified to three trays for younger learners or in time-constrained settings.

The LEGO brick taxa we created are biologically interconnected, descending from a common ancestor. Students are tasked with constructing a phylogenetic tree using LEGO brick taxa based on collaboratively chosen characteristics (e.g., color, number of bricks, or arrangement). As they analyze the trays representing earlier time

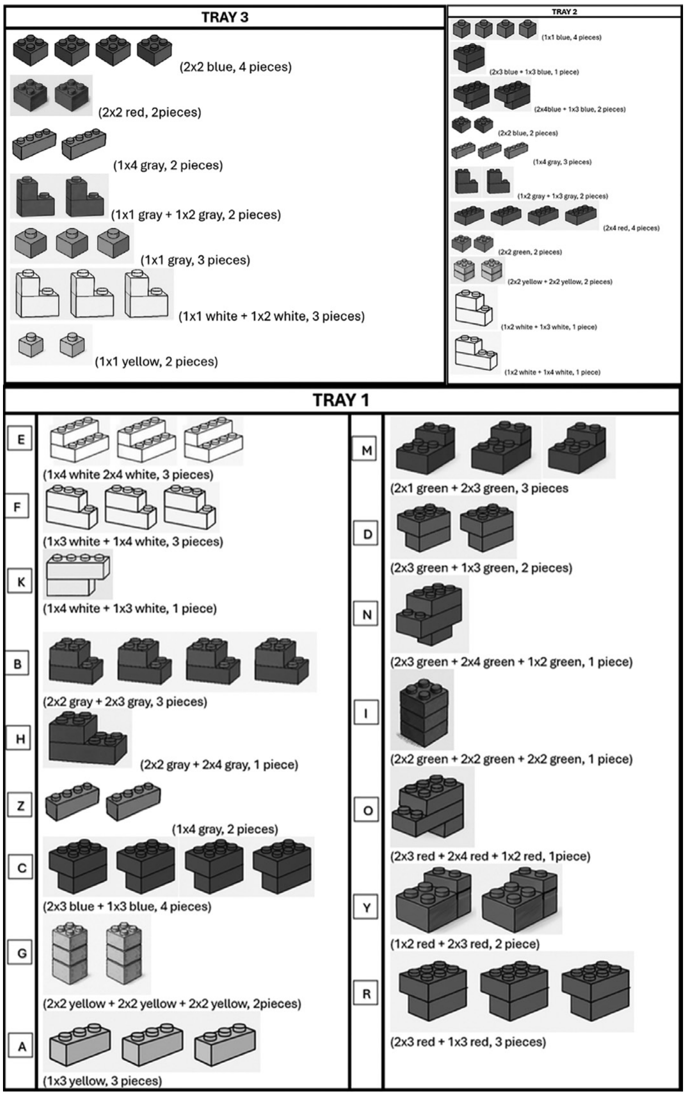

Figure 2. LEGO bricks in Trays 3, 2, and 1.

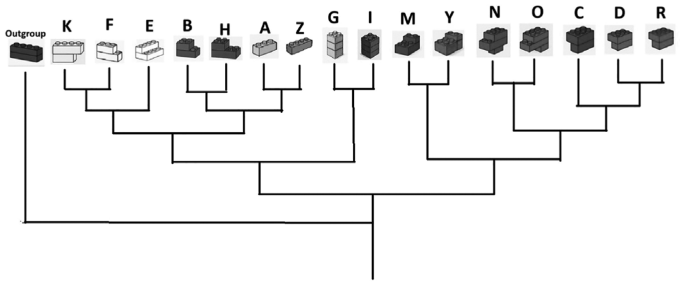

Figure 3. A hypothetical phylogenetic tree based on the fictional LEGO brick taxa

periods, students will observe the disappearance of certain traits (or evolutionary lineages) and identify evolutionary patterns. Our hypothetical phylogenetic tree based on our LEGO brick taxa is shown in Figure 3.

Instructors are encouraged to use this tree as a discussion tool for the following steps:

- Identifying which traits were likely used to justify each grouping
- Exploring alternative trees that could result from emphasizing different traits
- Introducing character matrices and how synapomorphies are mapped onto branches
- Reflecting on the provisional nature of scientific models and how they evolve with new data

○ Points to Consider in the Application

To mitigate potential misconceptions, we recommend explicitly stating to students that the White and Yellow LEGO taxa together form a monophyletic group, which shares a more recent common ancestor than either does with the Green group. In this way, the tree can be interpreted as representing two main clades descending from a single ancestor:

- **Clade X:** White + Yellow
- **Clade W:** Green

Clarifying this point reinforces accurate evolutionary thinking by emphasizing hierarchical relationships, shared derived traits (synapomorphies), and the principle of common ancestry. Moreover, acknowledging that even the Tray 4 organisms have ancestral forms not represented in the activity models helps prevent the mistaken view that Tray 4 taxa are the ultimate ancestors of all others. This explanation aligns the activity with accepted evolutionary principles while preserving the pedagogical benefits of structured variation.

It is also important to note that fossil record trays (Trays 2–4) served as modeled evidence, representing the kind of historical data used by scientists to reconstruct evolutionary relationships. Facilitators can guide students to treat each tray as a layer of scientific data and to revise their trees based on this accumulating evidence.

One of the key goals of the activity is not for students to produce a "correct" phylogenetic tree from the beginning. Rather, the activity is designed to help students revise and refine their tree as they encounter new information in earlier trays. This process mirrors the scientific method, where models and explanations evolve with accumulating evidence and where uncertainty (e.g., polytomies) and conflicting data (e.g., homoplasies) must be navigated through reasoning. This reinforces the core principle of science: models and explanations must be continuously updated as new evidence becomes available. In this way, the activity helps students appreciate the evolving nature of scientific knowledge.

It is essential to clarify that this activity does not portray evolution as a straightforward progression toward greater complexity. While some lineages do acquire more intricate trait combinations over time, others may evolve simpler forms in response to ecological and selective pressures. This activity explicitly avoids suggesting that evolution follows a linear or progressive trajectory. Instead, it encourages students to analyze character evolution as a branching, dynamic process influenced by selection and trait divergence. Environmental pressures such as changes in habitat, resource availability, or competition play a critical role in shaping evolutionary trajectories. These pressures influence which traits provide a selective advantage and therefore impact on the patterns of descent and divergence observed in phylogenetic trees. Through this activity, students explore how traits emerge, disappear, or are retained across time, and construct phylogenetic trees that reflect the branching, dynamic nature of evolutionary history.

Before or during the activity, it would be useful to provide explanations on certain topics to avoid misconceptions among participants. It should be stated that the organisms created in this simulation are models constructed by human consciousness. However, evolutionary processes do not occur within the framework of consciousness. It is important to address this misconception through the explanation. In addition, each created example can be perceived as an individual organism. Therefore, it should be clarified that these examples represent the average of a population. This will help convey the concept that evolutionary processes are driven by changes in gene frequency within the gene pool of populations, not individual organisms.

○ Activity Steps (90–120 minutes)

Step 1: Introduction to Phylogenetic Trees (Estimated Time: 5–45 minutes, depending on student readiness)

- Begin with a concise overview of phylogenetic trees, focusing on the key concepts of monophyletic vs. non-monophyletic grouping on a tree and how to interpret them.
- Depending on the learners' background knowledge, this introduction may be expanded to include the following:
  - o Characters used in phylogenetic analysis, including apomorphic (derived) and plesiomorphic (ancestral) traits.
  - o Methods of phylogenetic tree construction based on morphological and/or genetic data.
  - o The dynamic nature of systematics, with references to
    - the fossil record,
    - evolutionary innovations and extinction events,
    - mechanisms of evolution (e.g., natural selection, genetic drift, sexual selection), and
    - speciation processes.
- Highlight the role of morphological and genetic data in inferring evolutionary relationships and constructing phylogenies.
- In our implementation with pre-service biology teachers, this step was completed in approximately 5 minutes, as participants already had prior exposure to phylogenetic concepts. Instructors should adjust the duration and depth of this section according to the students' grade level and background knowledge.

Step 2: Group Formation (3–5 minutes)

- Form groups, assign group names, and distribute blank sheets for phylogenetic tree construction.

Step 3: Initial Phylogenetic Tree Construction (40–45 minutes)

- Distribute Tray 1 (Figure 4), which represents present-day populations of LEGO brick organisms distributed across different regions of a fictional Earth.
- Instruct participants to examine the LEGO organisms carefully and to identify morphological characters (e.g., number of bricks, size, color, arrangement, symmetry, vertical vs. horizontal orientation).
- Ask each group to select a set of morphological characters they consider informative and use those to begin constructing a hypothetical phylogenetic tree. The focus should be on identifying shared derived traits (synapomorphies) to infer relationships. Encourage them to distinguish informative traits from arbitrary similarities.
- Clarify that different groups may use different criteria, and that multiple tree topologies may be valid given the data.
- Encourage groups to discuss their reasoning aloud:
  - o Why did they group certain organisms together?
  - o Which traits are considered ancestral versus derived?
  - o How did they resolve conflicts (e.g., organisms that are structurally identical but differ in color)?
- Emphasize that this initial tree is a working hypothesis, and that it will likely change as participants encounter additional data from earlier trays (fossil record). The goal is not perfection, but rather engagement in scientific reasoning and recognition of the need to revise models as new evidence becomes available.

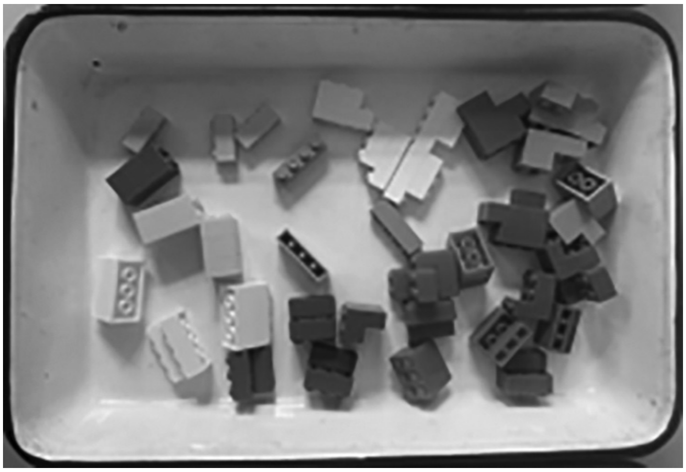

Figure 4. Tray 1 with present-day creatures in the fictional Earth.

Step 4: Introduction of Fossil Records (20–25 minutes)

- Present Tray 2 (Figure 5), representing fossil records from 10 million years ago.
- Instruct participants to reassess and revise their initial phylogenetic trees by incorporating the new data.
- Facilitate discussions on how fossil traits influence tree structure.

Steps 5 & 6: Additional Time Layers (10–15 minutes each for steps 5 & 6)

- Repeat the process with Tray 3 (20 million years ago) and Tray 4 (30 million years ago) (Figure 6).
- As participants integrate new data, emphasize changing biodiversity, extinction of lineages, and emergence of new traits across evolutionary time.

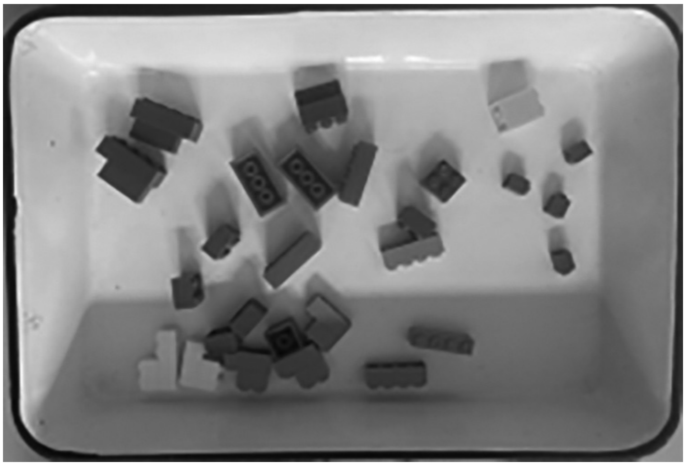

Figure 5. Tray 2 with fossil records from 10 million years ago.

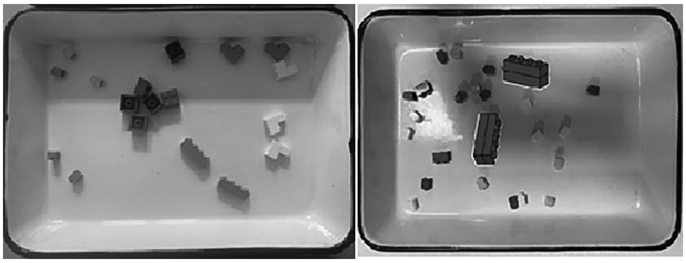

Figure 6. Tray 3 and Tray 4 with fossil records from 20 million (left) and 30 million years ago (right).

- Encourage students to reflect on how earlier traits persist, disappear, or transform.

Step 7: Strategy Reflection & Presentation Preparation (30 minutes)

- Ask participants to reflect on the strategies used in each step and prepare a 5-minute presentation describing their final tree, key traits used in grouping, how fossil data changed their interpretation, and challenges or uncertainties they encountered.

Step 8: Group Presentations (10–20 minutes)

- Groups present their phylogenetic trees, explaining their strategies and justifications.
- Facilitate group discussion around the differences in tree structures across groups, trait selection priorities, and insights into how scientific models evolve with new evidence.

Step 9: Group Discussion & Conceptual Review (30 minutes)

- Facilitate a whole-group discussion on the characteristics observed during tree construction.
- Show a hypothetical phylogenetic tree based on the trays (Figure 3). This tree represents one possible interpretation of evolutionary relationships and is not the only valid solution. Alternative trees could be constructed depending on the selected traits and character changes inferred.
- Summarize key concepts: common ancestry and descent with modification, role of environmental pressures and evolutionary mechanisms, trait divergence and convergence (homoplasy), importance of interdisciplinary evidence (e.g., morphology + fossils).
- Facilitate a reflection on the nature of science, emphasizing its cumulative, collaborative, and evolving character.
- Encourage participants to propose further questions for scientific inquiry.

This phylogenetic tree was generated using traits that students could readily observe and compare. While the structure appears detailed, several nodes contain polytomies—unresolved relationships that reflect either simultaneous divergence or limited trait resolution. Additionally, potential homoplasies (e.g., repeated appearance of red or green bricks) invite discussion about convergent evolution and trait weighting.

○ Data Gathering & Assessment

Evaluate presentations based on the clarity of the phylogenetic trees, incorporation of multiple data sources, and the depth of understanding demonstrated in reflections. Distribute an open-ended survey to gather participant feedback about the activity (see Appendix A provided as Supplemental Material with the online version of this article).

○ Follow-Up for Pre-Service Teachers

Use these follow-up procedures for pre-service teachers

- Discuss potential extensions or modifications for the activity.
- Encourage participants to explore further applications in their teaching practices.
- Emphasize the importance of dynamic, inquiry-based approaches in biology education.

○ Alternative Application

In addition to the traditional hands-on approach, integrating visual documentation through photos or drawings might provide an alternative layer to the activity. Participants can capture the trays with their mobile phones or tablets, facilitating a more versatile and detailed analysis. This alternative approach enhances the observational and analytical skills of participants, aligning with the principles of scientific inquiry.

Another alternative approach could involve students drawing separate phylogenetic trees for each tray. This method is ideal for lower grades and is also suitable when time is limited.

○ Findings

Student Phylogenetic Tree Constructions

Figure 7 illustrates phylogenetic trees constructed by Group 1, Group 2, and Group 3, respectively, during the activity. Each group developed a distinct tree structure based on their interpretation of the LEGO model traits and the fossil record presented in sequential trays.

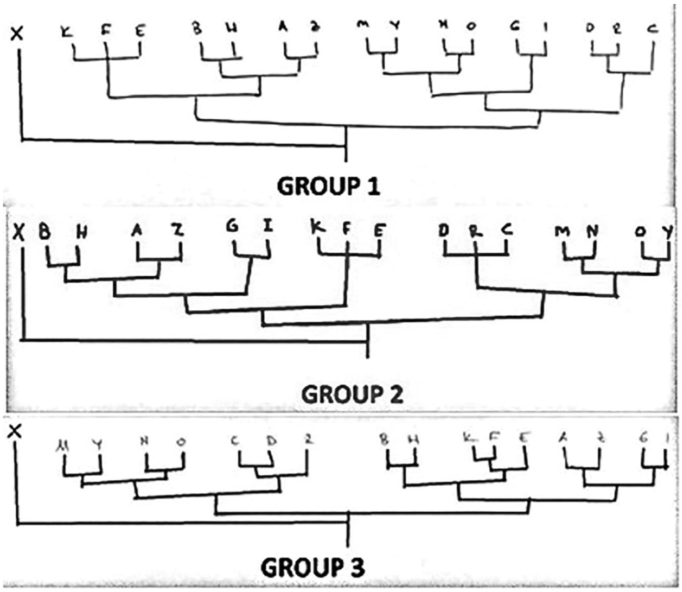

Figure 7. Phylogenetic trees of Group 1, 2 and 3.

As interpreted from the three phylogenetic trees compared with the target tree in Figure 6, Group 1 created the most accurate phylogenetic tree among the participants. In their tree, taxa that are closely related share a common ancestor, aligning well with key principles of evolutionary relationships and tree-thinking. All groups consistently rooted the tree with the outgroup in the correct position.

A major strength across all group trees was the students' ability to organize seemingly complex LEGO organisms based on selected traits (e.g., color, shape, orientation). This demonstrated an initial capacity to group organisms using observable features. However, integrating new data—especially from earlier fossil trays—posed challenges. Many students struggled to revise their initial hypotheses when new organisms did not fit neatly into existing groupings. This revealed a need for more structured guidance on how to incorporate new evidence into phylogenetic models.

Most students began by grouping organisms based on general similarity, such as color or size. Over time, however, they encountered inconsistencies that challenged this approach. Through group discussion and comparison across trays, they recognized that shared derived traits (synapomorphies) provided a more reliable basis for inferring evolutionary relationships. Several groups revised their trees to reflect synapomorphy-based branching.

All three groups successfully identified and represented major clades in a way that was broadly consistent with the instructor's reference tree. Each group was able to split the LEGO taxa into at least two major lineages, capturing the hierarchical structure expected in tree-thinking exercises.

During the activity, students noticed that some traits appeared to be lost or reappeared in different taxa, prompting discussion around possible homoplasies. They discussed why morphologically similar taxa might not share a recent common ancestor and reflected on convergent evolution and trait reversal. These observations enriched their understanding of the complexity inherent in real-world phylogenetics.

The final trees constructed by the groups generally displayed a clear, branching structure, avoiding circular or typological groupings. This suggests that students understood the importance of hierarchical relationships in phylogenetic reasoning. However, since the LEGO organisms were created through human design, it was necessary to remind students that real evolutionary change is not intentional. The artificiality of the models was acknowledged in pre-activity discussions to prevent misconceptions.

Ultimately, the students moved beyond typological thinking. While early tree constructions were often based on superficial resemblance, students learned that morphological similarity alone is not sufficient for establishing evolutionary relationships. In later stages, they were able to distinguish between ancestral (plesiomorphic) and derived (apomorphic) traits, leading to more accurate representations of lineage divergence. Some morphologically similar taxa were correctly placed in separate lineages based on their evolutionary history rather than visual similarity. This shift in reasoning demonstrated meaningful engagement with core concepts of phylogenetics.

After conducting the activity, the participants were given an open-ended survey (see Appendix A provided as Supplemental Material with the online version of this article) to gather information about their experiences of the activity.

○ Participants' Understanding & Perception of the Activity

Most participants' survey findings demonstrated a clear grasp of the activity's purpose, linking it to concepts such as phylogenetic classification, evolutionary processes, and common ancestry. Pre-service teachers valued the challenges associated with phylogenetic classification, describing their experience as reflective of real-world scientific practices. Many emphasized the importance of teamwork and group discussions in tackling complex problems. However, a few participants concentrated on the mechanical aspects of classification, such as the colors and shapes of the LEGO pieces, without making connections to broader evolutionary principles. This highlights the need for more explicit guidance during the activity. Emphasizing the various concepts mentioned in the introduction of the activity will be helpful in overcoming this difficulty.

Overall, the activity received positive feedback, with students appreciating its creative and hands-on approach. It successfully captured their interest, emphasized the complexity of classification and phylogenetic analysis, and promoted collaboration and problem-solving skills. While most participants found the activity enjoyable, some recommended extending the time allocated and providing clearer instructions to further enhance the learning experience.

○ Learning Outcomes

Pre-service biology teachers reported a solid grasp of phylogenetic classification, demonstrating an understanding of the complexity involved in analyzing multiple traits rather than focusing on individual characteristics. Several participants reflected on the process of constructing phylogenetic trees from fossil records and comprehended evolutionary relationships, including monophyletic and paraphyletic groupings. Others identified evolutionary patterns, such as the gradual emergence or disappearance of traits over time, highlighting the irreversible nature of extinction and the slow pace (such as 10 million years old) of evolutionary change.

When it came to evolutionary processes, some participants implied to correct misconceptions, emphasizing that evolutionary changes unfold over millions of years and that extinct species cannot reappear. Others explored the variability of traits within evolutionary branches, underscoring the importance of common ancestry.

The activity also heightened awareness of the challenges inherent in scientific research, with students recognizing the intricacy of constructing phylogenetic trees and the detailed nature of evolutionary studies. Collaborative group work during the activity helped uncover misconceptions and encouraged diverse perspectives.

Despite these successes, some misconceptions and gaps in understanding remained. A few participants demonstrated partial understanding, such as assuming species remain unchanged over time without acknowledging the role of environmental pressures. Others expressed confusion, signaling the need for further clarification in certain areas.

Lastly, participants gained valuable insights into the dynamic nature of evolution. Some articulated how species adapt by developing new traits, while others acknowledged that classification systems evolve as new data becomes available, illustrating flexibility in their thinking.

○ Strategies Used During the Activity

The participants employed several strategies during the classification process. Many of them started by classifying based on obvious features such as color or shape but recognized that more nuanced traits (e.g., number of segments, complexity) played a more significant role as they progressed. As the task progressed, they adapted their strategies, moving from surface-level traits to deeper features such as structure and evolutionary relationships. They built phylogenetic trees by iterating through these features, continuously refining their methods as new information was introduced. Additionally, a clear emphasis on teamwork was observed, with students relying heavily on group discussions and consensus-building to classify the LEGOs. It has been observed in one group that a student who did not defend their opinion made a more correct decision than the others, but because she did not defend it, she did not contribute to the group. This collaborative approach helped participants articulate their reasoning and enhance their critical thinking.

○ Activity Design & Suggestions for Improvement

The activity's design and suggested improvements highlight its suitability for different grade levels, intellectual demands, and educational benefits. Most participants agreed that the task is best suited for high school students, particularly those in 11th and 12th grades, or university students, due to their adequate background knowledge. Some participants felt that 8th-grade middle school students could engage with the activity, but it would require preparatory lessons on classification topics. Although the intellectual demands of the activity may be challenging for younger students, its emphasis on critical thinking, group collaboration, and scientific discussion is seen as highly beneficial. The activity fosters a deeper understanding of complex concepts such as phylogenetics, making it both engaging and memorable. To improve the experience, some suggested increasing the variety and quantity of materials, such as using alternatives such as toothpicks or matches to address confusion over LEGOs. Participants also recommended extending the time for more thorough discussions and iterative hypothesis testing or providing data upfront to streamline the process. To deepen the complexity, introducing ambiguous or incomplete data could encourage critical thinking, and discussions about future evolutionary changes, such as species extinction, would align with concepts such as adaptive radiation.

○ Challenges & Solutions

Several challenges emerged during the activity of classifying LEGO figures into a phylogenetic tree, highlighting difficulties in group consensus, representation complexity, and time management. Disagreements on classification criteria, particularly over prioritizing shape or color, led to debates resolved through discussion, patience, or voting, though earlier choices often required revision. Representing complex evolutionary transitions, such as the appearance and disappearance of traits, proved challenging, with groups simplifying their approach to prioritize clarity over exhaustive detail. Participants also struggled with conceptualizing evolutionary implications, such as trait reappearance, necessitating iterative refinements to their classifications. Uncertainty about the significance of certain features, such as holes in LEGO pieces or stagnant development, caused confusion, with confidence varying among members. Finally, time constraints pressured the group to streamline decision-making, leading to some compromises in depth and thoroughness. Despite these challenges, participants developed creative solutions and collaborative strategies to complete the task.

○ Conclusion

This tree-thinking LEGO activity offered valuable insights into both the challenges and successes of teaching phylogenetic classification. Participants demonstrated a strong grasp of evolutionary concepts, such as monophyletic and paraphyletic groupings, and recognized the complexities of constructing phylogenetic trees. They actively engaged in critical thinking, refined their classification strategies, and collaborated to address misconceptions and identify patterns in evolutionary processes. The activity was praised for its creative, hands-on approach, which fostered deeper learning and teamwork. It was particularly well-suited for older high school and university students but required consideration of students' developmental levels, with suggestions for adjustments for younger learners. While the activity proved effective in encouraging group discussion and scientific reasoning, challenges such as classification criteria, representation complexity, and time constraints highlighted the need for clearer instructions and more time for discussions. Some gaps in understanding persisted, signaling the need for further clarification in certain areas. Despite these challenges, the activity successfully stimulated scientific thinking, problem-solving, and collaboration. We encourage teachers and educators to use this inquiry-based tree-thinking activity as a resource to enhance their lessons and develop their students' tree-thinking abilities.

We acknowledge that the preliminary implementation of this activity was limited in its methodological rigor. The feedback collected from pre-service teachers was qualitative in nature and primarily based on self-reported reflections. While this approach provided valuable initial insights into student engagement and perceived learning, it did not directly measure gains in phylogenetic understanding. To strengthen future iterations of this research, we plan to incorporate pre- and post-assessment tools or rubrics specifically targeting students' understanding of tree-thinking, synapomorphies, and evolutionary reasoning. Such tools will allow us to evaluate conceptual shifts more systematically and identify which aspects of the activity are most effective in promoting phylogenetic thinking.

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