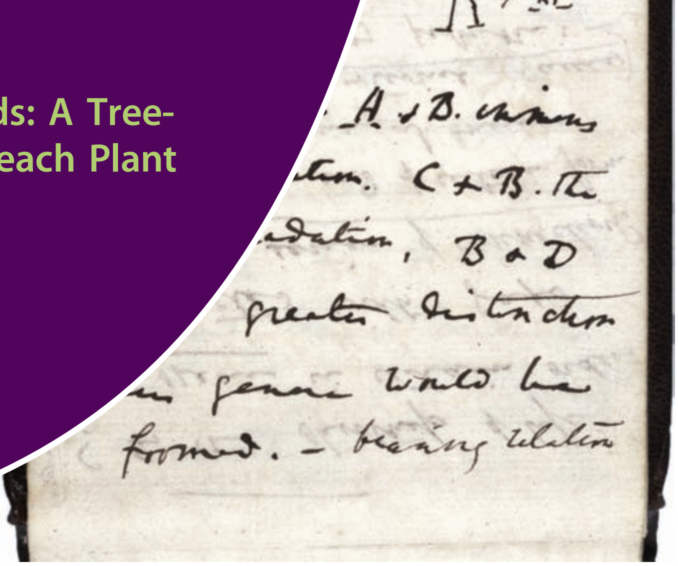
Botanical Phylo-Cards: A Tree-Thinking Game to Teach Plant Evolution



J. PHIL GIBSON, JOSHUA T. COOPER

Abstract

Students often have limited understanding of the major innovations in plant evolution. We developed a card sorting activity based on tree thinking that is suitable for students with a wide range of abilities and experience. Through this activity, students learn how scientists organize taxa into biologically meaningful, natural groups that illustrate important events in terrestrial plant evolution. The activity corresponds to several NGSS standards and is suitable for use in classroom or laboratory settings and as a public educational outreach activity.

The Botanical Phylo-Card Game *addresses several components of Next Generation Science Standards (NGSS Lead States, 2013) such as Inheritance/Variation in Traits (3-LS3-1, HS-LS3-1, HS-LS4-2) and Natural Selection/Evolution (MS-LS4-2, HS-LS4-1). The game involves disciplinary core ideas about biodiversity, evolution, and common ancestry; crosscutting concepts regarding identification and interpretation of patterns; and scientific practices of constructing explanations and engaging in arguments from evidence that can guide individualized implementation and assessment of the activity by different instructors.*

Key Words: *botany; phylo-card game; plants; evolution.*

○ Introduction

Botany and evolution are two topics about which students often lack fundamental awareness or knowledge and hold a number of misconceptions (Uno, 1994; Wandersee & Schussler, 1999; Hershey, 2004, 2005; Miller et al., 2006). Low botany and evolution literacy in students leaves them unable to fully appreciate the contributions of these fields to our understanding of the natural world. Consequently, students are unable to consider the many career options that involve plants or cannot critically evaluate issues ranging from the use of genetically modified crops to content of science curricula (Ward et al., 2014; Pew Research Center, 2015; National Research Council, 2016). Many excellent, inquiry-based modules for the classroom and laboratory have been developed to improve student understanding of botany and evolution separately, but there are relatively few quick activities suitable for use across grade levels that bring these topics together.

Botany and evolution are two topics about which students often lack fundamental awareness or knowledge and hold a number of misconceptions.

The Botanical Phylo-Card Game described here was originally developed as a booth activity for a STEM outreach event. It was intended to quickly teach booth visitors fundamental botanical and evolutionary concepts through a combination of tree thinking and card sorting. "Tree thinking" collectively refers to the analytical skills and knowledge of evolution necessary to interpret the information about relationships and evolution in phylogenetic trees. It is a powerful framework for teaching fundamental principles of evolution that can increase students' understanding and acceptance of evolution (Gibson & Hoefnagels, 2015). After successful use at the public outreach event, we discovered that combining tree thinking and card sorting is an effective way for students to demonstrate their understanding of evolution and features of the taxa being studied. This activity also helps teachers rapidly identify misconceptions and evaluate students' level of disciplinary expertise and approach to problem solving (Chi et al., 1981; Smith et al., 2016).

○ Materials

The Botanical Phylo-Card Game integrates elements of the Great Clade Race (Goldsmith, 2003) and the Phylogenetic Analysis of Plants (Gibson & Cooper, 2014), activities developed for high school and undergraduate biology courses. The game requires two sets of 27 cards. Cards in Sets A and B have a picture, the common name, and the scientific name

Downloaded from http://online.ucpress.edu/abt/article-pdf/79/3/241/59518/abt_2017_79_3_241.pdf by guest on 03 March 2021

The American Biology Teacher, Vol. 79, No 3, pages. 241–244, ISSN 0002-7685, electronic ISSN 1938-4211. © 2017 National Association of Biology Teachers. All rights reserved. Please direct all requests for permission to photocopy or reproduce article content through the University of California Press's Reprints and Permissions web page, www.ucpress.edu/journals.php?p=reprints. DOI: https://doi.org/10.1525/abt.2017.79.3.241.

of identical plant species on the front of the cards (Figure 1). Set B also has icons printed on the front of the cards and patterns of colored dots on the back. Icons represent different plant traits (Figure 2). Dot patterns broadly represent ribulose bisphosphate carboxy-oxygenase large subunit (*rbcL*) gene sequence data. Each set has one alga, two bryophytes, four seedless vascular plants, six gymnosperms, two basal angiosperms, seven eudicots, and five monocots. Playing card size (Supplement A, Supplement B) or a larger size cards for visually impaired students (Supplement A Large, Supplement B large) can be printed, cut, folded, and laminated using supplemental files. (See the Supporting Material at the end of this article.)

Figure 1. Example of Set A cards (top row) and Set B cards (bottom row), showing traits on the fronts of the columbine and whisk fern cards and rbcL dot patterns for the cactus card on the back.

○ Procedure

The fundamental idea of the game is to have players sort cards into groups. Their groupings are a hypothesis of the relationships among the species. The player then tests their hypothesis using genetic data represented by patterns of colored dots, and interprets what their groupings indicate about important traits in plant evolution. As a type of warm-up, players should be informed that characteristics or DNA sequences show patterns, and biologists try to understand the information in the patterns to group organisms. A nested pattern of relationships can be developed when similar patterns are used to group organisms together, and unique patterns are used to differentiate groups. For example, consider the dot color and texture patterns shown in Figure 3. The patterns could be a proxy for nucleotide sequences in this explanation. The three species are grouped together based on shared, similar dots in positions 1 and 4. However, the difference in position 2 between species C and species A and B, in conjunction with the shared similarity between A and B, places the two species in a sub-group together. Species A and B are placed in separate groups based on their difference at position 3. A more detailed activity to demonstrate genetic variation and groupings can be found in Ofner (2010).

In the first round of the game, a player (individual or small team) is given the cards in Set A and asked to sort them into groups of related species based on whatever traits they choose. After sorting, the player should explain the rationale for their groupings. Individuals should report back to the class and discuss the similarities and differences in observed traits that they used to group cards. Often this will result more from gross phenotypic similarity than strong evolutionary trend. After the discussion, these cards are set aside, with the groupings retained.

For the second round, the player is given cards from Set B with the dot patterns upward and asked to sort them into groups based on the *rbcL* dot patterns. After the second sorting round, the player again explains the rationale for groupings and compares

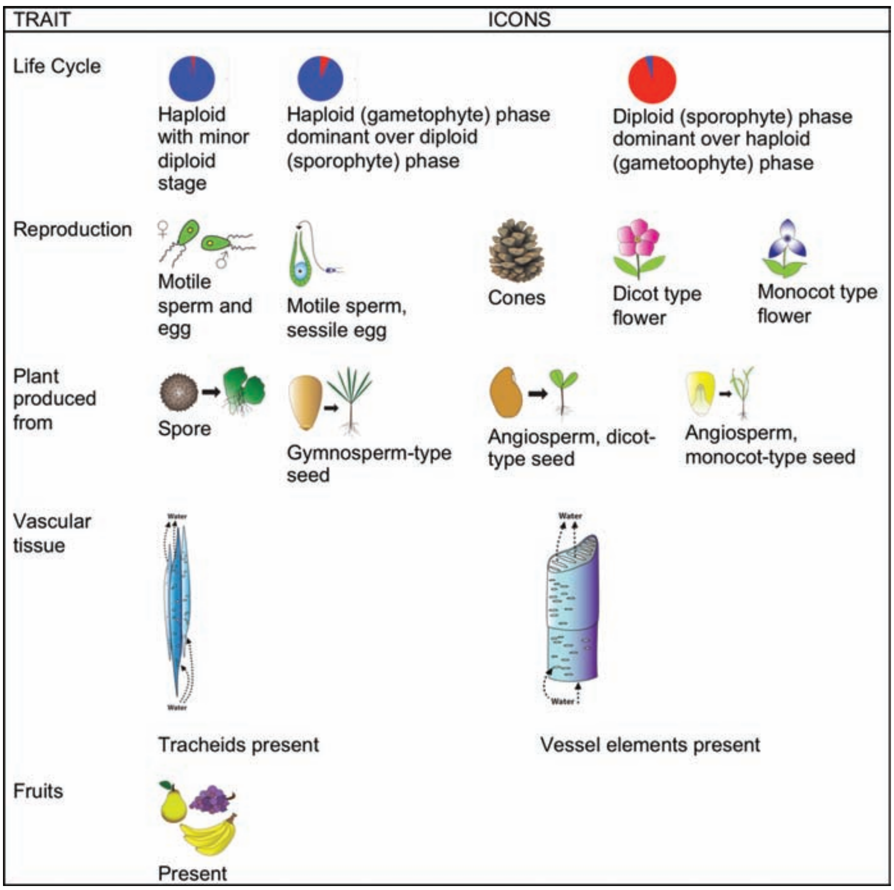


Figure 2. Key to plant traits on Set B cards.

Downloaded from http://online.ucpress.edu/abt/article-pdf/79/3/241/59518/abt_2017_79_3_241.pdf by guest on 03 March 2021

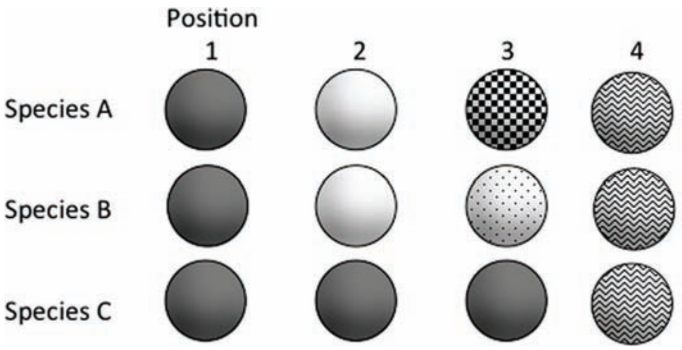


Figure 3. Example of how dot patterns can be used to differentiate and group taxa.

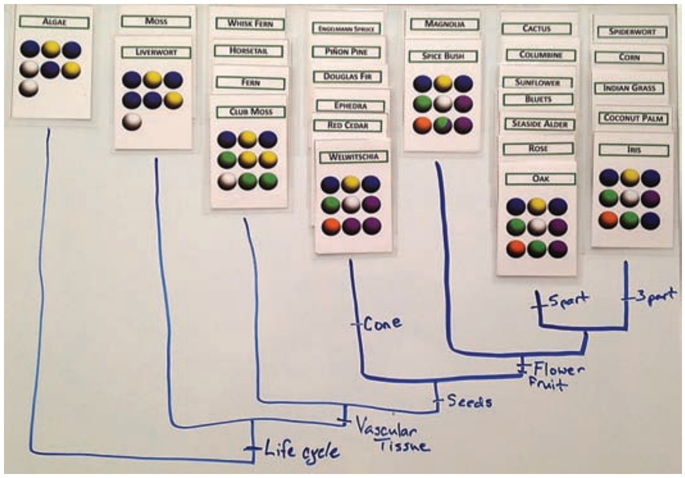


Figure 4. Example of phylogeny based on round two sorting of Set B cards.

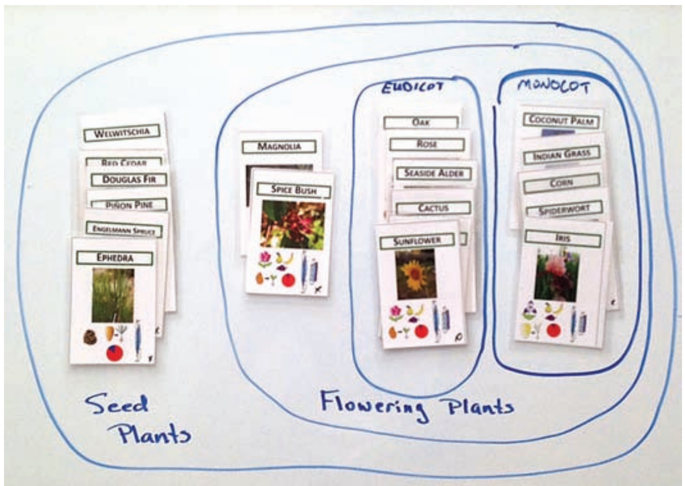


Figure 5. Example of nested organization of Set B cards after round two sorting.

how they are similar to and different from the first round groupings. After comparing and contrasting their groupings, the Set B cards are turned over to show the pictures and icons. The player is now asked to describe whether the groupings based on dots show any patterns with regard to the plant traits. Students should also explain how their *rbcL* data groupings relate to the traits of the different species. At this point, students should discuss how comparisons of groupings based on the dots (i.e., gene sequence data) could be used as an independent data set to support interpretations of how other traits evolved in plants. Patterns in the genetic data represented by dots and the patterns of traits should also be used to guide the discussion and highlight concepts of data congruence and identify the major events in plant evolution.

To complete the activity, round two groupings are then used to demonstrate how biologists use phylogenies to graphically display relationships among species and trait evolution. By placing the cards on a large sheet of paper or whiteboard, a tree diagram can be drawn to unify their groupings (Figure 4). Traits such as vascular tissue, use of motile sperm, or production of fruits can then be mapped on the phylogeny. A tree can also be drawn for the first round groupings to show how they are less parsimonious and give a confused perspective on trait evolution. Nested, hierarchical groupings can also be shown by drawing circles around groupings to further illustrate phylogenetic principles in grouping taxa (Figure 5). At this point, students should discuss how the diagrams show the sequence of how different traits arose over the course of plant evolution and the importance of reproductive traits in plant evolution.

A head-to-head variation can be used to take a slightly different approach to exploring the topic. Using two complete sets of cards, two individuals or teams play in a head-to-head competition to sort identical Set A cards as quickly as possible and explain their rationale as described above. Typically, there will be a number of differences between competitors' groupings after the first round. For the second round, teams sort the Set B cards as quickly as possible. However, one team uses the side with pictures and icons, and the other team uses the side with *rbcL* data. Except for occasional minor differences, the groupings are predominately identical, which further highlights data congruence.

○ Assessment

Sorting in the first round is typically based on superficial similarities that put distantly related species into the same group (e.g., palms, ferns, and cycads by the gross morphological similarities of leaves) or exclude related species from a group (e.g., grasses excluded from angiosperms with showy flowers). In the second round, groupings based on the dot patterns are often dramatically different from the first round. Players can usually explain how heritable genetic data indicated by the *rbcL* dots can be used to identify large, inclusive groups and differentiate smaller, more exclusive groups. They also identify traits such as the types of flowers, which segregate some plants into more exclusive groups, and other traits, such as the presence of vascular tissue, which delimit larger, more inclusive groups. The general sequence of vascular tissues evolving first, followed by evolution of seeds and flowers, is also evident after the second round.

When comparing phylogenies drawn from the first and second round groupings, the first round groupings are usually less parsimonious as a result of numerous homoplasies. Players typically organize species into accurate natural groupings using the trait icons or *rbcL* dot patterns. After comparing phylogenies, students discover how shared traits show common ancestry among taxa,

Downloaded from http://online.ucpress.edu/abt/article-pdf/79/3/241/59518/abt_2017_79_3_241.pdf by guest on 03 March 2021

but unique traits differentiate lineages. Students will also begin to build a framework to understand key innovations in plant evolution.

○ Conclusions

The Botanical Phylo-Card Game provides a simple and effective platform to teach fundamental botany and evolution concepts. Wilkins (1988) accurately described plants as "the most important, least understood, and most taken for granted of all living things." Dobzhansky (1973) famously stated, "Nothing in biology makes sense except in the light of evolution." More recent expansions on that idea note, "Nothing in evolution makes sense except in the light of phylogeny" (Society of Systematic Biologists, 2001), and "Nothing in evolution makes sense except in the light of DNA" (Kalinowski et al., 2010). Through a simple, card-sorting activity, we bring these four ideas together in a way that engages learners in discovering how botanists use evolutionary principles of tree thinking to understand the history and diversity of plants. We tested the activity with hundreds of players ranging from elementary school students to senior citizens, in addition to many undergraduates. In all instances, players quickly learned key events and trends in plant evolution and demonstrated understanding of how biologist use tree thinking.

○ Supporting Material

Phylocards in a standard playing card format and a larger size are available at http://www.ou.edu/gibsonlab/Tree_Thinking/Tree-Thinking_Modules_%26_Lab_Exercises.html

○ Phylocard Image Credits

Algae: By Frank Fox, http://www.mikro-foto.de, CC BY-SA 3.0 de https://commons.wikimedia.org/w/index.php?curid=20240900 https://en.wikipedia.org/wiki/Volvox#/media/File:Mikrofoto.de-volvox-4.jpg

Corn: By burgkirsch, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=1078541 https://en.wikipedia.org/wiki/Maize#/media/File:Maispflanze.jpg

Welwitschia: CC BY-SA 3.0 https://en.wikipedia.org/wiki/Welwitschia#/media/File:Welwitschia-mirabilis-female.jpg

All other images: © 2016 J. Phil Gibson

○ Acknowledgments

Development of the *Botanical Phylo-Card* Game was partially supported by NSF DUE #0940835 awarded to JPG. We thank the editors and reviewers for insightful comments, and acknowledge the assistance of Peter Gibson, Robert Gibson, and Maggie Gibson in early development and beta-testing the activity.

References

Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5,* 121–152.

Dobzhansky, T. (1973). Nothing in biology makes sense except in the light of evolution. *American Biology Teacher, 35,* 125–129.

Gibson, J. P., & Cooper, J. T. (2014). Phylogenetic approach to teaching plant diversity. Available from http://planted.botany.org/index.php?P=FullRecord&ID=546 (login required, see "Associated files").

Gibson, J. P., & Hoefnagels, M. H. (2015). Correlations between tree thinking and acceptance of evolution in introductory biology students. *Evolution: Education And Outreach, 8,* 15. doi:10.1186/S12052-015-0042-7

Goldsmith, D. (2003). The great clade race: Presenting cladistic thinking in both biology majors and general science students. *The American Biology Teacher, 25,* 679–682.

Hershey, D. R. (2004). Avoid misconceptions when teaching about plants. Retrieved from http://www.actionbioscience.org/education/hershey.html

Hershey, D. R. (2005). More misconceptions to avoid when teaching about plants. Retrieved from http://www.actionbioscience.org/education/hershey3.html

Kalinowski, S. T., Leonard, M. J., & Andrews, T. M. (2010). Nothing in evolution makes sense except in the light of DNA. *CBE-Life Sciences Education, 9,* 87–97.

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

National Research Council. (2016). Developing a national STEM workforce strategy: A workshop summary. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: National Academies Press.

Ofner, S. (2010). Using the NCBI genome databases to compare the genes for human and chimpanzee beat hemoglobin. *The American Biology Teacher, 72,* 4, 252–256.

Pew Research Center. (2015). *Public and Scientists' Views on Science and Society*. Retrieved from http://www.pewinternet.org/files/2015/01/PI_ScienceandSociety_Report_012915.pdf

Smith, J. I., Combs, E. D., Nagami, P. H., Alto, V. M., Goh, H. G., Gourdet, M. A. A., . . . , & Tanner, K. D. (2016). Development of the biology card sorting task to measure conceptual expertise in biology. *CBE- Life Sciences Education, 12,* 628–644.

Society of Systematic Biologists. (2001). Support for the teaching of evolution and scope of systematic biology, Society of Systematic Biologists. http://systbio.org/teachevolution.html (accessed 1 July 2010).

Uno, G. E. (1994). The state of precollege botanical education. *American Biology Teacher, 56,* 5, 263–267.

Wandersee, J. H., & Schussler, E. E. (1999). Preventing plant blindness. *American Biology Teacher, 61,* 84–86.

Ward, J. R., Clarke, H. D., & Horton, J. L. (2014). Effects of a research-infused botanical curriculum on undergraduates' content knowledge, STEM competencies, and attitudes toward plant sciences. *CBE—Life Science Education, 13,* 387–396. doi:10.1187/cbe.13-12-0231

Wilkins, M. (1988). *Plantwatching*. New York: Macmillan.

J. PHIL GIBSON is a Paul G. Risser Innovative Teaching Fellow and an Associate Professor in the Department of Microbiology and Plant Biology and the Department of Biology at the University of Oklahoma, Norman, OK, 73019; e-mail: jpgibson@ou.edu. JOSHUA T. COOPER is a doctoral student in the Department of Microbiology and Plant Biology at the University of Oklahoma, Norman, OK 73019; e-mail: jtcooper@ou.edu.

Downloaded from http://online.ucpress.edu/abt/article-pdf/79/3/241/59518/abt_2017_79_3_241.pdf by guest on 03 March 2021