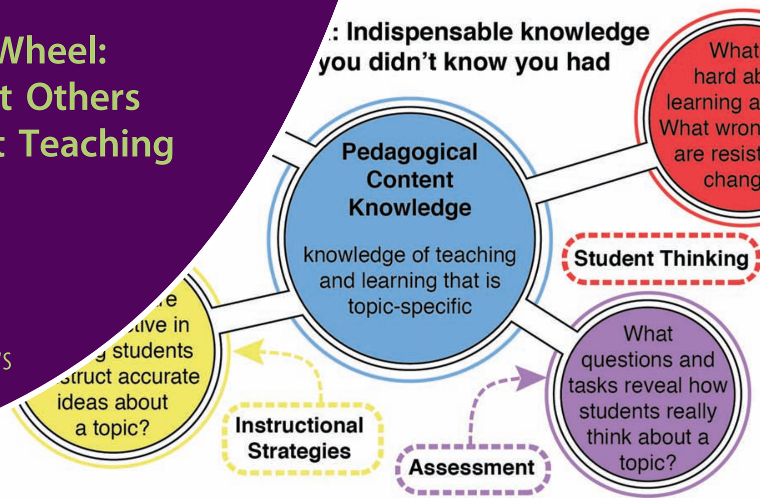
Don't Reinvent the Wheel: Capitalizing on What Others Already Know about Teaching Topics in Evolution



MICHELLE A. ZIADIE, TESSA C. ANDREWS

Abstract

What knowledge do you need to be an effective instructor? One key type of knowledge is pedagogical content knowledge (PCK), which includes awareness of how students are likely to think about a topic and where they will struggle as they learn that topic. We propose PCK as a valuable framework for reflecting on your own knowledge for teaching topics in evolution. We have created a searchable file that uses PCK as a framework to organize over 400 peer-reviewed papers from 40+ journals to give you better access to relevant resources for teaching evolution to undergraduates and advanced high school students. None of us have time to read 400 papers to inform our teaching, so we provide tips to maximize your use of this collective knowledge in the time you have available. We have written these to be useful to instructors across career stages.

Key Words: *Evolution education; undergraduate; teaching evolution; PCK; pedagogical content knowledge; student thinking; instructional strategies; teaching strategies; assessment; learning objectives.*

Take a moment to reflect on the knowledge that you use when you teach evolutionary topics. Most obviously, you use knowledge of the discipline of evolutionary biology. You also use pedagogical content knowledge (PCK). PCK combines content knowledge of a specific topic with knowledge about how students will interact with that topic as they learn (Magnussen et al., 1999; Park & Oliver, 2008; Gess-Newsome, 2015). Most often we build PCK through teaching experience, but could we also benefit from the published work of veteran evolution instructors and education researchers? We think so. Our aim in this article is to guide you to recognize the PCK that you may already have and to encourage you to capitalize on collective knowledge to continue to build PCK for teaching topics in evolution.

You have been using and building PCK since you started learning to teach. For example, imagine you pose this question to your students and they write down their thoughts: "A species of fish lacks fins. How would biologists explain how a species of fish without fins evolved from an ancestral fish species with fins?" (Nehm et al., 2012). Now reflect: What kinds of answers do you expect from your students? Could you predict a difficulty your students would have with this question? Maybe you predicted that undergraduates would have a much harder time answering this question accurately than one about how traits become common through natural selection (Nehm & Ha, 2011). Or maybe you thought about how students would be likely to explain that fins evolved away because the fish didn't "need" them anymore (Bishop & Anderson, 1990). If so, you were relying on PCK for teaching natural selection.

PCK is central to many parts of teaching. We use PCK when we decide what learning objectives for a topic are important and reasonable for students to achieve and what objectives are less crucial and can be cut if we run out of time. We employ PCK when predicting what makes a topic particularly hard to learn and where students might get stuck. During instruction we use PCK when drawing on specific analogies, visual representations, or activities that we know are useful in helping students construct accurate understandings. Additionally, we rely on PCK when writing in-class questions and exam questions that reveal what students actually know about a topic. Importantly, what is challenging about learning (and therefore teaching) one topic is often entirely different than what is challenging about learning the next topic, so we depend on distinct PCK for each topic we teach.

As a result, the body of PCK we need as evolution instructors is staggering! What if we could supplement our personal PCK by drawing on the collective knowledge others have already built through experience and research? This knowledge can be referred to as "collective PCK." Collective PCK is generated by researchers and instructors and made publicly available for others. We have taken steps to make collective PCK in peer-reviewed literature more readily available. We hope this makes it more useful to college and AP Biology instructors at all career stages.

We created a searchable file that organizes over 400 peer-reviewed papers about undergraduate and high school evolution instruction from over 40 different journals (see https://www.lifescied.org/doi/suppl/10.1187/cbe.17-08-0190). You can read more

The American Biology Teacher, Vol. 81, No. 2, pp. 133–136, ISSN 0002-7685, electronic ISSN 1938-4211. DOI: https://doi.org/10.1525/abt.2019.81.2.133.

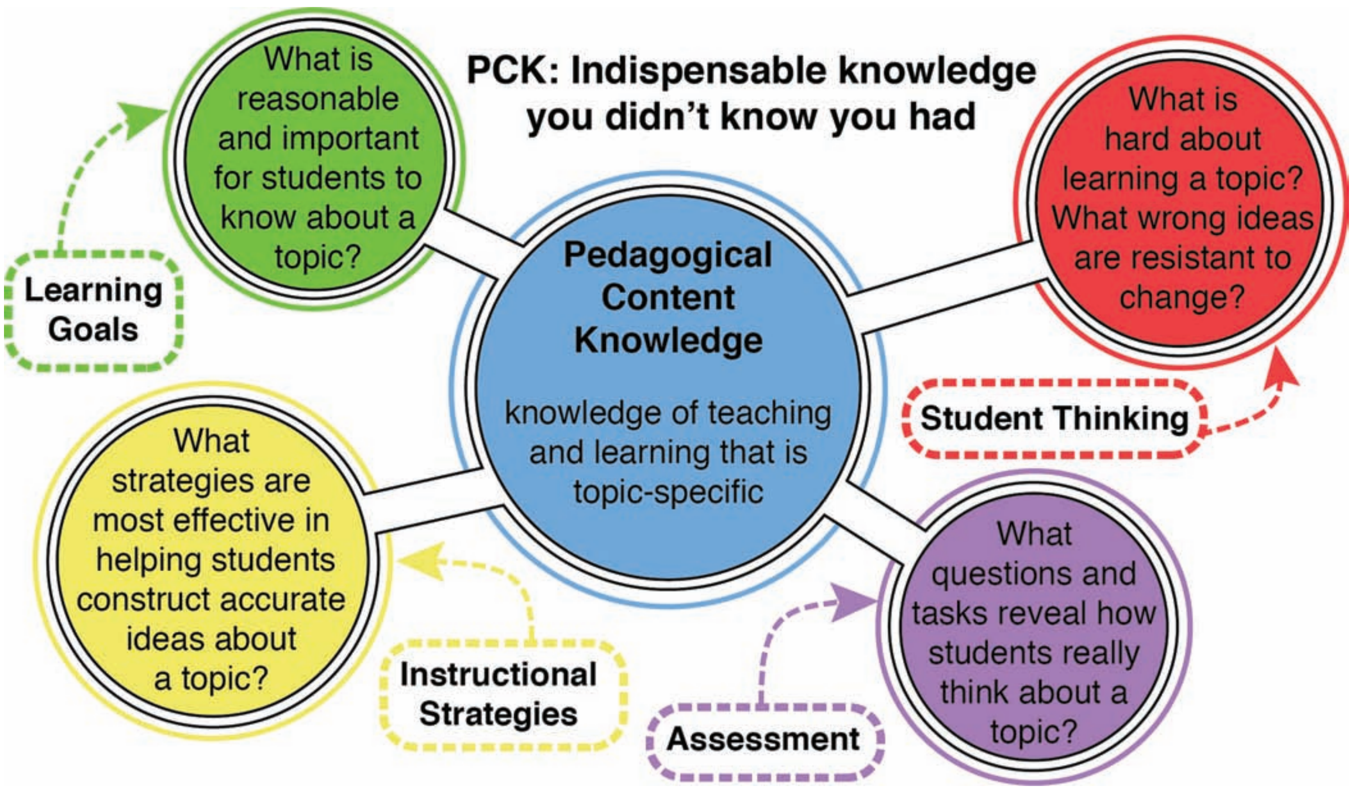


Figure 1. Pedagogical content knowledge: the indispensable knowledge you didn't know you had.

about how we identified, screened, and analyzed these papers in Ziadie & Andrews (2018). None of us have time to read 400 papers to inform our teaching, so here are some tips to maximize your use of this collective knowledge in the time you have available.

○ Tip 1: Use the Searchable File to Strategically Identify Peer-Reviewed Papers That Meet Your Specific Needs

The searchable file organizes each paper by several characteristics so that you can find just what you are looking for. Papers are organized by the area of instruction (student thinking, instructional strategy, assessment, learning goals), the type of work (empirical, descriptive, author's perspective, literature review), evolution topic(s) (e.g., genetic drift, speciation, population genetics, human evolution), publication year, and journal. For example, if you are preparing to teach a lesson about phylogenetics and you want an evidence-based activity to challenge your students, you can sort the file by "phylogenetics," "type," and "instructional strategies." You would find eight papers that describe empirical investigations (i.e., type = empirical) of an instructional strategy for teaching phylogenetics to undergraduates and another 24 papers that describe instructional strategies but do not investigate their effectiveness (i.e., type = descriptive). This searchable file is freely available as a supplemental material with Ziadie and Andrews (2018) at https://www.lifescied.org/doi/10.1187/cbe.17-08-0190.

○ Tip 2: Prioritize Papers about Student Thinking

An awareness of how students are likely to think about a topic is central to all facets of teaching. Knowing what prior ideas students will have and what difficulties they may experience as they learn a topic will help you design student-centered learning objectives, assessments, and instruction. There are different types of work that present collective PCK about student thinking. We recommend starting with literature reviews, which condense what researchers have discovered and thus provide high return on invested time. For many evolutionary topics, there have been too few empirical investigations of undergraduate thinking to warrant a literature review (Ziadie & Andrews, 2018). In those cases, there is significant value in reading a single study that describes in detail the ideas students commonly have about a topic.

○ Tip 3: Not Sure Where to Start? Here Are Five Papers That We Highly Recommend

- *Gregory (2009)*. Though natural selection seems logical – even intuitive – to a biologist, it is consistently challenging for undergraduates to learn. Many students retain major misconceptions about natural selection, even after carefully planned instruction (e.g., Nehm & Reilly, 2007; Andrews et al., 2011). This literature review summarizes the specific difficulties students encounter in learning natural selection. This is particularly useful because the misconceptions that students invoke as they think about other topics, such as genetic drift and evolutionary development, are often rooted in misunderstandings of natural selection (Andrews et al., 2012; Hiatt et al., 2013; Price & Perez, 2016).

- *Gregory (2008)* and *Meisel (2010)*. Being able to read phylogenetic trees is a key step in developing understanding of evolutionary relationships. It is also very hard. Without targeted instruction many students leave college courses unable to interpret even simple trees (e.g., Novick & Catley, 2007). For example, students often think that the order of terminal nodes in a tree indicates relatedness and so assume that two nodes that are physically closer to each other are more closely related (Baum et al., 2005; Meir et al., 2007). Gregory (2008) reviews accurate and inaccurate ways to read phylogenetic trees and describes common misconceptions. Meisel (2010) focuses on the two most common misconceptions and suggests approaches to helping students overcome these challenges.
- *Mead & Scott (2010a)* and *Mead & Scott (2010b)*. Terms used in evolutionary biology often have different meanings in everyday life. For example, scientists use the term *random* to refer to unpredictability of a given event but students often interpret *random* to mean purposeless or meaningless. In fact, it is common for students to think that random processes are not important in biological systems (Garvin-Doxas & Klymkowsky, 2008). This two-part essay series highlights problematic terms in teaching evolution and suggests research-based solutions. Keeping in mind how the terminology we use might be heard by students prevents inadvertently promoting inaccurate ideas.

○ Tip 4: Create Opportunities to Learn from Your Students

What topics are particularly difficult for your students? Do you know why they struggle? Pick a topic that you expect to be challenging and that you would like to rethink in your teaching, and use your students as confidential informants to learn how they think about this topic. You can learn about student thinking in class by asking all students to write a response to an open-ended question on notecards (Angelo & Cross, 1993). A quick read through these cards will reveal a wide variety of thinking and some patterns that you might not anticipate. You can learn even more in conversations with students. Invite students with a range of performance to office hours and ask them probing questions with the goal of uncovering their thinking. Some prompts that we find useful are "What do you mean when you say...?" and "Tell me more about that." It is also informative to ask students to discuss how one concept relates to another. Try to get a complete picture of what a student is thinking before giving any feedback. You may be surprised by how much you learn!

○ Conclusion

Our work focused on cognitive components of evolution education rather than work related to students' beliefs, acceptance, and attitudes regarding evolution. We recognize that such work can be highly valuable to instructors, but it was outside the scope of the research that produced the searchable file. We recommend a recent essay that presents a framework, reviews relevant research, and recommends teaching practices to reduce perceived conflict between evolution and religion and increase acceptance of evolution among students (Barnes & Brownell, 2017).

○ Acknowledgments

We would like to thank Raheela Charania, Dustin Dial, and Nnaji Emetu for their assistance with the research that made this essay possible. Thanks to Allen Moore for reminding us not to make unnecessary work for ourselves. We would also like to thank the UGA Biology Education Research Group for constructive feedback and support throughout this work. Partial funding was provided by a National Science Foundation Graduate Research Fellowship awarded to M.A.Z. (grant no. DGE-1443117). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

Andrews, T.M., Leonard, M.J., Colgrove, C.A. & Kalinowski, S.T. (2011). Active learning not associated with student learning in a random sample of college biology courses. *CBE–Life Sciences Education*, *10*, 394–405.

Andrews, T.M., Price, R.M., Mead, L.S., McElhinny, T.L., Thanukos, A., Perez, K.E., et al. (2012). Biology undergraduates' misconceptions about genetic drift. *CBE–Life Sciences Education*, *11*, 248–259.

Angelo, T.A. & Cross, K.P. (1993). *Classroom Assessment Techniques: A Handbook for College Teachers, 2nd ed*. San Francisco, CA: Jossey Bass.

Barnes, M.E. & Brownell, S.E. (2017). A call to use cultural competence when teaching evolution to religious college students: introducing Religious Cultural Competence in Evolution Education (ReCCEE). *CBE–Life Sciences Education*, *16*, es4.

Baum, D.A., Smith, S.D. & Donovan, S.S. (2005). The tree-thinking challenge. *Science*, *310*, 979–980.

Bishop, B.A. & Anderson, C.W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching*, *27*, 415–427.

Garvin-Doxas, K. & Klymkowsky, M.W. (2008). Understanding randomness and its impact on student learning: lessons learned from building the Biology Concept Inventory (BCI). *CBE–Life Sciences Education*, *7*, 227–233.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. In A. Berry, P. Friedrichsen & J. Loughran (Eds.), *Re-examining Pedagogical Content Knowledge in Science Education* (pp. 28–42). New York, NY: Routledge.

Gregory, T.R. (2008). Understanding evolutionary trees. *Evolution: Education and Outreach*, *1*, 121.

Gregory, T.R. (2009). Understanding natural selection: essential concepts and common misconceptions. *Evolution: Education and Outreach*, *2*, 156–175.

Hiatt, A., Davis, G.K., Trujillo, C., Terry, M., French, D.P., Price, R.M. & Perez, K.E. (2013). Getting to evo-devo: concepts and challenges for students learning evolutionary developmental biology. *CBE–Life Sciences Education*, *12*, 494–508.

Magnussen, S., Krajcik, J. & Borko, H. (1999). Nature, source, and development of pedagogical content knowledge. In J. Gess-Newsome & N.G. Lederman (Eds.), *Examining Pedagogical Content Knowledge* (pp. 95–132). Dordrecht, The Netherlands: Kluwer.

Mead, L.S. & Scott, E.C. (2010a). Problem concepts in evolution part I: purpose and design. *Evolution: Education and Outreach*, *3*, 78–81.

Mead, L.S. & Scott, E.C. (2010b). Problem concepts in evolution part II: cause and chance. *Evolution: Education and Outreach*, *3*, 261–264.

Meir, E., Perry, J., Herron, J.C. & Kingsolver, J. (2007). College students' misconceptions about evolutionary trees. *American Biology Teacher*, *69*, e71–e76.

Meisel, R.P. (2010). Teaching tree-thinking to undergraduate biology students. *Evolution: Education and Outreach*, *3*, 621–628.

Nehm, R.H., Beggrow, E., Opfer, J. & Ha, M. (2012). Reasoning about natural selection: diagnosing contextual competency using the ACORNS instrument. *American Biology Teacher*, *74*, 92–98.

Nehm, R.H. & Ha, M. (2011). Item feature effects in evolution assessment. *Journal of Research in Science Teaching*, *48*, 237–256.

Nehm, R.H. & Reilly, L. (2007). Biology majors' knowledge and misconceptions of natural selection. *BioScience*, *57*, 263–272

Novick, L.R. & Catley, K.M. (2007). Understanding phylogenies in biology: the influence of a gestalt perceptual principle. *Journal of Experimental Psychology: Applied*, *13*, 197.

Park, S., & Oliver, J.S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, *38*, 261–284.

Price, R.M. & Perez, K.E. (2016). Beyond the adaptationist legacy: updating our teaching to include a diversity of evolutionary mechanisms. *American Biology Teacher*, *78*, 101–108.

Ziadie, M.A. & Andrews, T.C. (2018). Moving evolution education forward: a systematic analysis of literature to identify gaps in collective knowledge for teaching. *CBE–Life Sciences Education*, *17*, article 11.

MICHELLE A. ZIADIE (michelle.ziadie@uga.edu) is a Ph.D. candidate and TESSA C. ANDREWS (tandrews@uga.edu) is an Assistant Professor, both in the Department of Genetics, University of Georgia, Athens, GA 30602.