Theoretical Ecology (2022) 15:143–146
https://doi.org/10.1007/s12080-022-00533-1

ORIGINAL PAPER

Diverse perspectives from diverse scholars are vital for theoretical biology

Allison K. Shaw[1]

Received: 1 October 2021 / Accepted: 3 March 2022 / Published online: 26 March 2022

Abstract
Science is based on studying some aspects of the world while holding others constant. The assumptions of what can and cannot be ignored implicitly shape our understanding of the world around us. This truth is particularly evident when studying biology through mathematical models, where one must explicitly state assumptions during the process of model building. Although we often recognize that all models are "wrong" in their assumptions, we often overlook the corollary that developing multiple models that are wrong in different ways can help us triangulate truth in our understanding. Theoretical biologists build models in the image of how they envision the world, an image that is shaped by their scientific identity, experiences, and perspectives. A lack of diversity in any of these axes handicaps our ability to understand biological systems through theory. However, we can overcome this by collectively recognizing our own assumptions, by understanding how perspective shapes the development of theory, and — most importantly — by increasing the diversity of theoretical biologists (in terms of identity, experiences, and perspectives). Combined, this will lead to developing theory that provides a richer understanding of the biological world.

Keywords Assumptions · Bias · Diversity · Mathematical model · Theory

Perspectives shape science

Scientific studies typically focus on some aspects of the world while holding constant (ignoring) other aspects. Such a narrowing of perspective is essential for making progress in understanding; studying everything simultaneously would quickly become overwhelming. Yet, this approach also requires making judgment calls as to what will be explored and what will be ignored.

The assumptions of what can and cannot be ignored implicitly shape our understanding of the world around us. Only that which is studied can be understood. Systematically taking the same perspective, and thus systematically assuming away the same things, creates gaps in our knowledge. Here are several examples. The effect of biological sex was historically ignored; before 2014, the majority of research animals (from model organisms in the lab to clinical trials in humans) were male, limiting our ability to understand both female biology and sex differences (Ogden 2021). Zebrafish are a common model system for studying behavior, yet how this behavior is shaped by parasites was ignored until recent work demonstrated that parasite infection alters fish behavior and that infections are widespread, but variable, among lab populations (Spagnoli et al. 2017). Gut microbes (which make up 99% of the microbes in humans) were ignored until the past two decades, but are now recognized to have a variety of impacts on their hosts (Moran et al. 2019). Mutualistic interactions are ubiquitous in ecological systems, yet they have historically been short-changed relative to competitive interactions in ecological textbooks due to a number of biases ranging from taxonomic to political (Bronstein 2015). And there are many many more ways our implicit assumptions shape our understanding, some of which we are not yet even aware of.

The identities, experiences, and perspectives of researchers shape their view of the world and thus the questions they ask. Although this is true for everyone, it is most easily seen for researchers who are in a minority along one of these axes. For example, Karen Warkentin's personal experience with transitions (moving between different countries, coming out as queer) informs the transitions she studies: frogs

✉ Allison K. Shaw
ashaw@umn.edu

[1] Department of Ecology, Evolution and Behavior, University of Minnesota-Twin Cities, Saint Paul, MN 55108, USA

that move between aquatic and terrestrial habitats through their life cycle (Gabrielle 2017). Joseph Graves Jr.'s experience with racism, as an African American evolutionary biologist, shapes his work on anti-racism (Graves 2019). Robin Wall Kimmerer's childhood experiences in the woods and her identity as a member of the Citizen Potawatomi Nation drive her research interests in restoring both ecological communities and human relationships with the land (Kimmerer 2013). Joan Roughgarden's scientific interests in sexual diversity are shaped by her experience with the San Francisco gay community (Gewin 2003). Each of these scientists has faced push back on their ideas, since they called attention to things that had previously been ignored and assumed to be unimportant.

Theory has bias

The above ideas hold across all science, yet the field of theoretical biology faces additional sources of perspective bias. Building a mathematical model of a biological system is effectively a four step process (Fig. 1): (1) posing a question about a system, (2) translating the biological system into a mathematical model, (3) analyzing the model, and (4) interpreting the mathematical result biologically. In particular, the act of translating biology into math requires making assumptions about what to ignore, assumptions that are shaped by the theorist's perspective. For example, most models of biological invasions assume no Allee effect despite this being a widespread biological phenomenon (Gascoigne et al. 2009) with clear effects on invasions (Taylor and Hastings 2005). As another example, most models of how individual variation affects group dynamics like collective behavior take a narrow perspective of variation, considering only a small number of fixed individual "types" and overlooking the rich axes of variation seen in empirical systems (Delgado et al. 2018). It should come as no surprise that translator identity and perspective, as well as cultural context, shape the translation of biology into math. Indeed, this concept is well established for textual translation like poetry (Weinberger and Paz 1987). Yet, the role of theorist identity in shaping mathematical theory is rarely discussed or taught. Following the step of translation, the analysis step of model building also includes assumptions shaped by the theorist's perspective. For example, much of ecological theory has focused on equilibrium assumptions, overlooking transient dynamics (Hastings 2004). As another example, many models of evolutionary ecology assume separation of timescales between ecological and evolutionary processes (Lion 2018).

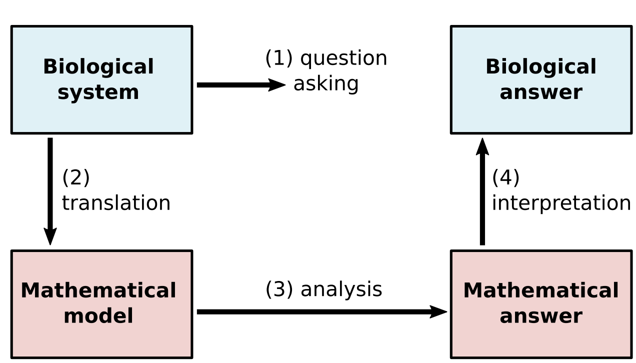

Fig. 1 A schematic of theoretical biology as a four-step process, linking the realms of biology (in blue) and mathematics (in red). Step 1: ask a question about a biological system. Step 2: translate the biological system into a mathematical model. Step 3: analyze the model to get a mathematical answer. Step 4: interpret the mathematical answer to get a biological answer

Thus, we are left with a paradox. At its core, modeling is the act of understanding the link between assumptions and outcomes. Yet, we often think of math as objective and we fail to account for subjective aspects of making specific assumptions and seeing them through to their conclusion. Another way to see this conflict is that although it is well recognized, and often overquoted, that "all models are wrong" (i.e., they make simplifying assumptions), the corollary of this is often overlooked: developing models that are wrong in different ways provides a better understanding of a system than any one model alone can. Or, as Levins (1966) put it, "our truth is the intersection of independent lies."

Taken together, these ideas indicate that any collective bias in how theorists build and analyze models will lead to a collective bias in our understanding of biological systems. This outcome is especially problematic since theory, of which mathematical models are only one part, provides the intellectual scaffolding that we use to make sense of empirical findings (Schaechter 2012). If we neglect certain sets of assumptions and research directions, we will miss critical pieces of scaffolding, which in turn will handicap our ability to make sense of the world. One way this manifests is when we summarize a body of theory. If five models with the same core assumptions give the same answer, this provides no more generality than a single model. Multiple models only contribute to a broader understanding to the extent that they differ in their underlying assumptions. Thus, a diversity of modeling approaches, and the assumptions underlying them, is vital for good theory.

Theoretical biology lacks diverse perspectives

Unfortunately, theoretical biology as a field lacks the diverse perspectives that foster diverse modeling approaches. Although few, if any, studies have quantified diversity of scholar identities explicitly for mathematical biology (Lee and Clinedinst 2020), this subfield lies at the intersection of the fields of mathematics and biology, which each lack diversity in their scholar composition (Herzig 2004; Taylor 2010; Shaw and Stanton 2012). Intuitively then, mathematical biology would similarly lack diversity. Indeed, scholars in most scientific disciplines do not reflect the diversity of identities and experiences present in the broader human population (National Science Foundation, National Center for Science and Engineering Statistics 2019).

These observations should lead us to ask, "what is it about our environment that prevents this diversity from being cultivated?" (Montgomery 2020). One answer is recruitment — how students start, are trained, the language(s) they communicate in, and whether they feel a sense of belonging (Tardy 2004; Good et al. 2012; Shaw and Stanton 2012; Lee and Clinedinst 2020; O'Brien et al. 2020). A second answer is retention — how differential failed retention of scholars by identity contributes to misrepresentation (Puritty et al. 2017; Shaw et al. 2021) and thus loss of their perspectives. We must consider the role of our academic environment, even though doing so requires the more uncomfortable action of looking inward, rather than outward. Only by getting curious about our environment of academia and how it selects for or against certain perspectives, experiences, and identities (and in turn the scholars that hold them) can we understand how to shift these selective pressures and, in turn, the composition of scholars in theoretical biology and across academia.

Ways forward

Theoretical biologists build models in the image of how they envision the world, an image that is shaped by their scientific identity, experiences, and perspectives. Thus, cultivating a diversity of scholars (with diverse identities, experiences, and perspectives) can help ensure a diversity of assumptions and, in turn, reduce bias in our understanding of the world (Intemann 2009). Accomplishing this goal requires reexamining our academic environment to make it a place that is welcoming to diverse perspectives and the scholars who hold them. Others have written recently about ways to accomplish this in the broader field of biology (Bhalla 2019; Cooper et al. 2020; Cronin et al. 2021). Here are some ways to do so for mathematical biology, specifically.

1. Be mindful of the subjective assumptions that go into models and avoid the fallacy (of both theorists and non-theorists alike) that because math seems objective, therefore math models are objective.
2. Recognize (both individually and collectively) our own assumptions and understand how our identities, experiences, and perspectives shape the development of our theory.
3. Seek out new experiences and perspectives to uncover assumptions we did not even know we were making, and to reshape our views of the biological world and in turn the models we develop to describe it.
4. Seek out a range of collaborators with identities, experiences, and perspectives that differ from our own. Encourage collaborators (and mentees) to bring their full identity to their work, instead of conforming to majority perspectives.
5. Think carefully when generalizing research from multiple models. Robustness of outcomes is only as strong as the diversity of assumptions that went into building them.
6. When teaching and training, show multiple models for the same biological system and discuss how researcher perspective shapes the model and thus the outcomes.

Combined, these steps will make our field more welcoming to a diverse set of scholars. In turn, this will lead to developing theory that provides a richer understanding of the biological world.

Acknowledgements I thank Daniel Stanton for many insightful conversations, María Rebolleda-Gómez for helpful feedback on an early draft, and two anonymous reviewers for feedback. I am grateful for the extra time to think enabled by a sabbatical from the University of Minnesota, and to the new perspective gained from being on sabbatical at l'Université de Montréal with support from Fulbright Canada.

Author contribution AKS conceived of and carried out the work and wrote the manuscript.

Funding This study was supported by Fulbright Canada.

Availability of data and material Not applicable.

Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication All persons entitled to authorship have been so named. The author has approved the submission of this manuscript for publication.

Conflict of interest The author declares no competing interests.

References

Bhalla N (2019) Strategies to improve equity in faculty hiring. MBoC 30:2744–2749. https://doi.org/10.1091/mbc.E19-08-0476

Bronstein JL (2015) The study of mutualism. In: Bronstein JL (ed) Mutualism. Oxford University Press, Oxford, UK, pp 3–19

Cooper KM, Auerbach AJJ, Bader JD et al (2020) Fourteen recommendations to create a more inclusive environment for LGBTQ+ individuals in academic biology. LSE 19:es6. https://doi.org/10.1187/cbe.20-04-0062

Cronin MR, Alonzo SH, Adamczak SK et al (2021) Anti-racist interventions to transform ecology, evolution and conservation biology departments. Nat Ecol Evol 5:1213–1223. https://doi.org/10.1038/s41559-021-01522-z

Delgado M del M, Miranda M, Alvarez SJ et al (2018) The importance of individual variation in the dynamics of animal collective movements. Philos Trans R Soc, B 373:20170008. https://doi.org/10.1098/rstb.2017.0008

Gabrielle V (2017) Bridging the gap between biology and gender studies: a Q&A with Karen Warkentin. Boston University News Service. http://bunewsservice.com/qa-with-karen-warkentin/

Gascoigne J, Berec L, Gregory S, Courchamp F (2009) Dangerously few liaisons: a review of mate-finding Allee effects. Popul Ecol 51:355–372

Gewin V (2003) A plea for diversity. Nature 422:368–369. https://doi.org/10.1038/422368a

Good C, Rattan A, Dweck CS (2012) Why do women opt out? Sense of belonging and women's representation in mathematics. J Pers Soc Psychol 102:700–717. https://doi.org/10.1037/a0026659

Graves JL (2019) African Americans in evolutionary science: where we have been, and what's next. Evo Edu Outreach 12:18. https://doi.org/10.1186/s12052-019-0110-5

Hastings A (2004) Transients: the key to long-term ecological understanding? Trends Ecol Evol 19:39–45. https://doi.org/10.1016/j.tree.2003.09.007

Herzig AH (2004) Becoming mathematicians: women and students of color choosing and leaving doctoral mathematics. Rev Educ Res 74:171–214. https://doi.org/10.3102/00346543074002171

Intemann K (2009) Why diversity matters: understanding and applying the diversity component of the National Science Foundation's Broader Impacts Criterion. Soc Epistemol 23:249–266

Kimmerer RW (2013) Braiding sweetgrass: indigenous wisdom, scientific knowledge, and the teachings of plants. Milkweed Editions, Minneapolis, MN

Lee S, Clinedinst L (2020) Mathematical biology: expand, expose, and educate! Bull Math Biol 82:120. https://doi.org/10.1007/s11538-020-00796-x

Levins R (1966) The strategy of model building in population biology. Am Sci 54:421–431

Lion S (2018) Theoretical approaches in evolutionary ecology: environmental feedback as a unifying perspective. Am Nat 191:21–44. https://doi.org/10.1086/694865

Montgomery BL (2020) Lessons from microbes: what can we learn about equity from unculturable bacteria? mSphere 5:e01046–20. https://doi.org/10.1128/mSphere.01046-20

Moran NA, Ochman H, Hammer TJ (2019) Evolutionary and ecological consequences of gut microbial communities. Annu Rev Ecol Evol Syst 50:451–475. https://doi.org/10.1146/annurev-ecolsys-110617-062453

National Science Foundation, National Center for Science and Engineering Statistics (2019) Women, minorities, and persons with disabilities in science and engineering: 2019. Special Report NSF 19–304. Alexandria, VA. Available at. https://www.nsf.gov/statistics/wmpd Accessed July 28 2021

O'Brien LT, Bart HL, Garcia DM (2020) Why are there so few ethnic minorities in ecology and evolutionary biology? Challenges to inclusion and the role of sense of belonging. Soc Psychol Educ 23:449–477. https://doi.org/10.1007/s11218-019-09538-x

Ogden LE (2021) How gender bias has shaped reproductive biology. Bioscience 71:216–222. https://doi.org/10.1093/biosci/biaa172

Puritty C, Strickland LR, Alia E et al (2017) Without inclusion, diversity initiatives may not be enough. Science 357:1101–1102. https://doi.org/10.1126/science.aai9054

Schaechter M (2012) Lynn Margulis (1938–2011). Science 335:302. https://doi.org/10.1126/science.1218027

Shaw AK, Accolla C, Chacón JM et al (2021) Differential retention contributes to racial/ethnic disparity in U.S. academia. PLoS One 16:e0259710. https://doi.org/10.1371/journal.pone.0259710

Shaw AK, Stanton DE (2012) Leaks in the pipeline: separating demographic inertia from ongoing gender differences in academia. Proc R Soc B 279:3736–3741. https://doi.org/10.1098/rspb.2012.0822

Spagnoli S, Sanders J, Kent ML (2017) The common neural parasite *Pseudoloma neurophilia* causes altered shoaling behaviour in adult laboratory zebrafish (*Danio rerio*) and its implications for neurobehavioural research. J Fish Dis 40:443–446. https://doi.org/10.1111/jfd.12512

Tardy C (2004) The role of English in scientific communication: *lingua franca* or *Tyrannosaurus rex*? J Engl Acad Purp 3:247–269. https://doi.org/10.1016/j.jeap.2003.10.001

Taylor CM, Hastings A (2005) Allee effects in biological invasions. Ecol Lett 8:895–908. https://doi.org/10.1111/j.1461-0248.2005.00787.x

Taylor DE (2010) Race, gender, and faculty diversity in environmental disciplines. In: Taylor DE (ed) Research in Social Problems and Public Policy. Emerald Group Publishing Limited, pp 385–407

Weinberger E, Paz O (1987) 19 ways of looking at Wang Wei. Asphodel Press, Kingston, Rhode Island