doi:10.1111/evo.13924

Gaming natural selection: Using board games as simulations to teach evolution

Morgan R. Muell,[1] Wilson X. Guillory,[1] Allison Kellerman,[1] Andrew O. Rubio,[1,2] Ayana Scott-Elliston,[1] Omar Morales,[1] Katie Eckhoff,[1,3] David Barfknecht,[1] Jeremy A. Hartsock,[1] Jennifer J. Weber,[1,4] and Jason L. Brown[1,5]

[1]*School of Biological Sciences, Southern Illinois University, Carbondale, Illinois*

[2]*Department of Biology, East Carolina University, Greenville, North Carolina*

[3]*Department of Ecology and Evolutionary Biology, University of Kansas, Lawrence, Kansas*

[4]*Department of Biology, Southeast Missouri State University, Cape Girardeau, Missouri*

[5]*E-mail: jasonleebrown@gmail.com*

Received November 2, 2019
Accepted December 26, 2019

The world is in the golden age of strategy board games, with thousands of new board games published each year, especially in the past decade (Beard 2016; BGG 2019). Recently, we have seen a rise in science-themed board games (Jolin 2019). Educational games have been around for decades, but the majority of the old guard are forgettable and dull, limiting their academic value. In the past decade, however, many educational games rival games intended purely for entertainment (e.g., Cytosis by Genius Games). The newest kids on the block are a slew of fun, high-quality evolution-themed board games, whose elaborate mechanisms and aesthetic beauty show great promise for engaging and teaching students (West 2015; Coil et al. 2017; Chuang 2017). Our research group (undergraduates, graduate students, and two professors) evaluated the utility of many of these newer games for scientific education in the field of evolution. We also integrated our top-ranked games into an upper-level college course that explored the mechanisms that drive the evolution and maintenance of biodiversity through geological time.

Distilling complex evolutionary concepts through seemingly simplistic models is commonplace in evolutionary biology. For example, John Maynard Smith famously used game theory to characterize Evolutionarily Stable Strategies (Maynard Smith 1972), and subsequently, game theory has been widely evoked to improve understanding of group selection (Queller 1984), sexual selection (Zahavi and Zahavi 1999), altruism (Hamilton 1971), parental care (Clutton-Brock and Godfray 1991), and coevolution (Brown and Vincent 1987). In a very general and broad framework, both game theory and board games emphasize strategy and consequences for decision makers (i.e., individuals or game players). Thus, it is not surprising that strategy-based board games naturally extend to evolution education. These board games can actually be used to simulate specific ecological and evolutionary elements, and therefore have wide utility in classrooms to emphasize curricula. Specifically, students can critically evaluate these board games in the context of evolution-based learning objectives by identifying which evolutionary concepts the games omit, get right, or get wrong. Evolution by its very nature tends to be subtle and coupled with stochastic processes, which, if perfectly emulated as a board game, would be dull and monotonous. As a result, board game designers abstract many of the ecological and evolutionary processes to facilitate game progression. Game designers also add extensive player agency to evolutionary "choices," which result in a more engaging experience, but at its core, produce an inherently flawed evolutionary simulation. And of course, board games typically proceed with a fixed "goal" over a finite time period, which is in glaring contrast with actually evolutionary processes. Despite these limitations, board games provide innovative ways to engage and motivate students in addition to traditional methods (Sharp 2012). Further, games are interactive and dynamic, which provides opportunities to reinforce key concepts and explore novel scenarios (Sharp 2012). Lastly, many learning objectives are integrated into these games, which can increase comprehension and academic performance (Schwartzman 1997; Saliés 2002).

For this project, we first explored and then critically evaluated 11 currently available evolution-themed strategy board games that

Table 1. Evolution games evaluated for education use.

Board game name	Publisher	Players	Complexity	Playtime (minutes)	Rank
A.D.A.P.T.	Gate Keeper Games	2	Medium	30	11
Bios: Genesis (second edition)	Sierra Madre Games	2–4	Heavy	90–120	3
Bios: Megafauna (second edition)	Sierra Madre Games	2–4	Heavy	90–120	2
Biosphere	DDD Verlag GmbH	2–6	Medium–Heavy	90	5
Darwin's Choice	Treeceratops	2–6	Medium	60–90	6*
Dominant Species	GMT games	2-6	Heavy	120–240	8
Evolution: The Beginning	North Star Games	2–5	Light	30–45	4
Evolution: Climate	North Star Games	2–4	Medium	60	1
Evo (second edition)	Asmodee Games	2–4	Medium	60	6*
Inhabit the Earth	Huch & Friends	2–4	Medium–Heavy	60–90	10
On the Origins of Species	Mont Taber	2–4	Medium	45	9

*Games tied.

appeared to have both high educational and entertainment value (Table 1). After many nights of heavy competition (and plenty of extinction events!), we settled on a hierarchy of the best evolution-themed games. We based our rankings on composite high scores comprising theme, complexity, educational value, and of course, entertainment value. Here, we present written reviews of four of our top evolution-themed board games: "Evolution: The Beginning," "Evolution: Climate," both by North Star Games; "Biosphere" by DDD Verlag GmbH; and "Bios: Megafauna (second edition)" by Sierra Madre Games. All four games have a strong link in gameplay to key biological concepts and, importantly, were a lot of fun to play. Our full rankings of each game and their potential educational value are presented in Table S1 and extended written reviews are available online at www.darwinsgamenight.org along with associated teaching materials. We also discuss how student-guided learning through modification of existing board games can further elevate conceptual comprehension and class discussions.

Top-Rated Board Games

The first game, *Evolution: The Beginning*, is a breezy Darwinian knife fight. Players "evolve" their species to outsmart other players' species competing for the same limited food. To get an edge, players can "adapt" their species to become carnivores (that now eat other species), increase foraging efficiency, or boost reproductive rate. Other predators can be avoided by evolving to become nocturnal, flying, or burrowing. Points are scored for the amount eaten during the game and for the number and quality of the species you have left at the game's end. The player with the most points wins.

Evolution: The Beginning is a great complement to an introduction to evolutionary theory. The small size and limited components make the game approachable for all types of students. It is particularly well-suited for teaching evolutionary arms races, adaptations, and interspecific interactions. In particular, we think the game is excellent for demonstrating how evolution has no foresight—a difficult concept for many students. Students first play the game by the publisher rules. Then students play a second time without looking at any of their trait cards, which are then randomly assigned to their species. Despite being simple and straightforward, *Evolution: The Beginning* is full of rich strategic decisions based on real evolutionary concepts.

Evolution: Climate elevates *Evolution: The Beginning* from a two-dimensional game, where players deal with the threats of starvation and predation, into a three-dimensional game by adding the effects of changing climates. In *Evolution: Climate*, the core framework presented in *Evolution: The Beginning* is maintained. However, the array of adaptations increases, and players also need to avoid extinction from changing climates. This can be done by evolving "heavy fur," "cooling frills," or by "migrating," depending on which climate crisis may be looming. Points are again scored by consuming food, and for the number and quality of the species you have left at the end of the game. The player with the most points wins.

Evolution: Climate is our top-rated evolution themed strategy board game for use as an educational resource. It is a phenomenal game, full of rich strategic and tactical decisions. The added complexity and interplay between the climate and species dramatically expand the potential uses for educational purposes. The gameplay, however, remains fairly simple to understand (and to teach). It is also worth noting that *Evolution: Climate*, and other games in the *Evolution* series, possess amazing and distinctive artwork. The imaginative and bright watercolor art perfectly weaves the elegance of gameplay with its evolutionary theme and definitely helps immerse players in the game. We think this game is a great hands-on activity to complement curricula on a variety of subjects, including evolutionary arms races, mass extinction events,

climate change (both future and past), ecological and evolutionary physiology, and interspecific interactions. However, given its complexity, instructors should be prepared for a range in comprehension by students using the game as part of a curriculum. We highly recommend both *Evolution* games for use in most high school or college classrooms.

We also played two more games that required a few hours to play due to their increased complexity: *Biosphere* and *Bios: Megafauna.* The length of gameplay and complexity narrow the breadth of their academic use, but also increase scientific realism, allowing for more in-depth connections to evolutionary concepts (e.g., the causes of the mass extinctions, or the demographic and genetic consequences of habitat configuration and change).

In *Biosphere*, players control a species at the dawn of its arrival to a vast uncolonized landscape. At the start of the game, each player's species is poorly adapted to the new landscape and can only survive a few years in each of the six biomes. During the game, players "evolve" their species to increase its reproductive rate, movement, and biome-specific lifespan. The core gameplay is driven by hundreds of small dice representing individuals, and their values represent that individual's remaining lifespan — a clever mechanic that adds realism to the game. As the game progresses, each species radiates across the mosaic of available biomes. Players win the game by achieving five randomly selected evolutionary goals associated with dominating a biome type(s), having the largest population, adapting to all biomes, or occupying a number of biome tiles.

Biosphere is one of the few evolution-themed games that are a mix of long-term strategic decisions and turn-to-turn tactics. The many randomly chosen goals also vary gameplay, which results in interesting and new challenges every game (see our house rules and additional gameplay materials for increased utility in the classroom on www.darwinsgamenight.org). *Biosphere* is a great companion to a curriculum on conservation biology, habitat ecology, and population genetics. We were also able to mix Biosphere with demographic and genetic computer simulations (e.g., see "connecting population genetics, demography and evolution" at www.darwinsgamenight.org).

Bios: Megafauna is an incredibly deep game that spans the last 500 million years on Earth and ends at the dawn of the Quaternary period. The game begins at the start of the Phanerozoic, where players attempt the long and difficult journey to evolve from a simple archetype of a plant, mollusk, insect, or vertebrate, to a much more complex species and dominate Earth's early biomes. Players compete to colonize ancient continents that are subject to dramatic tectonic activity, cosmic events, and changing atmospheres. The game ends at the dawn of the Quaternary, and the player with the highest population on Earth and highest species diversity (both extinct and living) wins.

This game is an absolute educational gem and could be used to reinforce many key evolutionary and geological concepts. This mostly stems from the fact that the core gameplay mechanisms are directly tied to actual geological events and key biological innovations. *Bios: Megafauna* and its sibling *Bios: Genesis*, which we also ranked highly, cover a broad array of topics that could reinforce classroom curricula. However, these games are incredibly complex, which makes them very difficult to teach. Most of our participants became overwhelmed at some point. We mitigated this by implementing a few house rules and ensured that there was someone who completely understood the rules that frequented each game group. Overall *Bios: Megafauna* is a rewarding mix of short-term strategy and tactics that will leave you pondering your decisions for days. However, the game was also quite punishing and left a few students sour from luck-based outcomes. Many times, these instances provided teaching opportunities and we would discuss the science behind negative events. For example, the Chicxulub Comet Impact at the Cretaceous–Paleogene boundary 66 million years ago released large quantities of SO_2 and carbonates into the atmosphere, which increased the greenhouse effect and, in combination with the Deccan Traps, increased global temperatures by 4°C (Bond and Grasby 2017). In the real world, these events caused mass extinctions; the game mimics this event by forcing many players to lose all or most of their species. Nonetheless, active discussions tied the game back to class material and helped to diminish negativity. Lastly, the complexity and the many situational rules make the game feel like a mix between a simulation and a strategy board game. Because of this, the game is entertaining, but does not beg for immediate replay.

Using Evolution-Themed Board Games in the Classroom

Our course was an introduction to historical and contemporary biogeography, and as we progressed through our curriculum, the associated games increased in complexity and spatio-temporal scope. We moved from population-level processes over short periods of time to global processes over half a billion years. This was intentional and provided a gateway to the more complex and rule-heavy games, particularly for students less familiar with strategy board games. In addition, to reinforce key concepts, the board games were also tied into course projects. For example, participants were tasked with developing and presenting a course curriculum associated with a key concept emulated in one of the board games. Students also modified one of the games so that the game better implemented key evolutionary or ecological concepts to increase the scientific accuracy and educational value. For example, several students

Table 2. Evolution games and the key concepts useful for education that were well executed.

Board game name	Concepts addressed well	Taxa included
A.D.A.P.T.	Evolutionary arms races, adaptations	Fishes
Bios: Genesis (second edition)	Chemical evolution and creation of biopolymers, origins of biological evolution, evolution of biological complexity and differentiation of organ functions, evolutionary transition from unicellular to multicellular organisms, biological consequences of geologic and cosmic events	Prokaryotes and eukaryotes
Bios: Megafauna (second edition)	Descent with modification, speciation, extinction, biological consequences of geologic and cosmic events, mass extinctions, historical biogeography, dispersal and immigration, continental drift, plate tectonics and their history, paleoclimatology, island biogeography, origins of higher cognition and emotions	Plants, mollusks, insects, vertebrates
Biosphere	Links between demography and habitat ecology, conservation biology, dispersal and immigration, carrying capacity, population ecology, Grinnellian niches	Terrestrial vertebrates
Darwin's Choice	Evolutionary arms races, environmental-based versus competition/predation-mediated adaptations, interspecific interactions, Grinnellian niches, evolutionary and ecological physiology	Broad range of vertebrates and a few invertebrates
Dominant Species	Natural selection, competition, dominance, Grinnellian niches	Insects, arachnids, amphibians, birds, reptiles, mammals
Evolution: The Beginning	Evolutionary arms races, interspecific interactions, foresight of evolution	Range of nonexisting terrestrial vertebrates
Evolution: Climate	Evolutionary arms races, environmental-based versus competition/predation-mediated adaptations, evolutionary and ecological physiology, interspecific interactions, biological consequences of geologic and cosmic events, mass extinctions	Range of nonexisting terrestrial vertebrates
Evo (second edition)	Evolutionary arms races, environmental-based versus competition-mediated adaptations, evolutionary and ecological physiology, interspecific interactions, Grinnellian niches, climate change	Dinosaurs
Inhabit the Earth	Global species diversity and distributions	Broad range of terrestrial vertebrates
On the Origins of Species	History of Darwin's voyage through the Galápagos	Plants and animals

modified the games to demonstrate the effects of urbanization, habitat fragmentation, climate change, and island biogeography. Other students modified games so they reflected different biomes (i.e., aquatic ecosystems) and different taxonomic groups (plant or microbe communities). Some students added probability in the outcomes of traditional binary outcomes, such as attack or reproductive success. Finally, a few students increased the biological realism of games by incorporating key ecological, evolutionary, or demographic processes. These ranged from community-driven behavioral processes, such as the landscape of fear, to implementing an explicit link between reproduction rate, resource availability, and carrying capacity. The diversity of students' biological interests paved the way to this broad array of projects reflecting different biological concepts, which enriched the overall learning experience beyond concepts reflected in board games alone.

These hands-on exercises required participants to think about the core biological processes of interest in context of the infrastructure and constraints of the associated board game. The medium to high tactile interactivity also resonated well with most of the participants, and they were eager to explore new strategies in their efforts to win.

Conclusion

None of these games perfectly emulated evolution, which we knew going into the course, and every game grossly convoluted the boundaries between intelligent design and natural selection. However, this was a deliberate and important decision by the game designers, as it provided agency to each player to directly "strategize" and permute different solutions to evolutionary success. Specifically, player agency in vested players in the game and its outcome. This resulted in dynamic gameplay, where rapid-arms races and intense competition drove players' "evolutionary" responses. Post-gameplay, we found that students greatly benefited from guided discussions on how each game succeeded and failed in emulating the core evolutionary and ecological concepts, which promoted critical thought by encouraging students to reflect on the experience.

Each game we reviewed brought its own strengths and pitfalls in the context of teaching evolution; although none were perfect, all offered different insights into biological processes (Table 2). Overall, board games present an interactive and fun experience for many types of curricula (Sardone and Devlin-Scherer 2016; Taspinar et al. 2016). We hope our evaluations can be a resource for instructors teaching many aspects of ecology and evolution. Notably, some of the greater insights we gained during our trial run were through students' course projects, drawn from their scientific backgrounds. Perhaps student innovation will pave the way forward to even higher quality games. Either way, we can attest that many of these evolution-themed board games meet the mark for entertainment both in and outside the classroom, and we encourage biology instructors at diverse academic levels to give them a try.

LITERATURE CITED

Beard, M. 2016. A data analysis of board game rankings. Available at www.bestplay.co/board-games-getting-worse. Accessed August 1, 2019.

BGG, Board Game Geek. 2019. Board Gamer Geek database of board games. Available at www.boardgamegeek.com. Accessed August 1, 2019.

Bond, D. P. G., and S. E. Grasby. 2017. On the causes of mass extinctions. Palaeogeogr. Palaeoclimatol. Palaeoecol. 478:3–29.

Brown, J. S., and T. L. Vincent. 1987. Coevolution as an evolutionary game. Evolution 41:66–79.

Chuang, A. 2017. Game changers. Science 355:587.

Clutton-Brock, T., and C. Godfray. 1991. Parental investment. Pp. 234–262. *in* J. R. Krebs, and N. B. Davies, eds. Behavioural ecology: an evolutionary approach. Blackwell Science, Oxford, U.K.

Coil, D. A., C. L. Ettinger, and J. A. Eisen. 2017. Gut Check: the evolution of an educational board game. PLoS Biol 4:15.

Hamilton, W. D. 1971. Selection of selfish and altruistic behavior in some extreme models. Pp. 57–91 *in* J.F. Eisenberg, W.S. Dillon, eds. Man and beast: comparative social bahavior. Smithsonial Institution Press, Washington, DC.

Jolin, D. 2019. The board games turning science into playtime. *The Guardian*. Available at www.theguardian.com/science/2019/apr/20/board-games-turning-science-into-playtime.

Maynard Smith, J. 1972. Game theory and the evolution of fighting on evolution. Edinburgh Univ. Press, Edinburgh.

Queller, D. C. 1984. Kin selection and frequency dependence: a game theoretic approach. Biol. J. Linn. Soc. 23:133–143.

Saliés, T. G. 2002. Simulation/gaming in the EAP writing class: benefits and drawbacks. Simul. Gaming 33:316–329.

Sardone, N. B., and R. Devlin-Scherer. 2016. Let the (board) games begin: creative ways to enhance teaching and learning. Clearing House 89:215–222.

Schwartzman, R. 1997. Gaming serves as a model for improving learning. Education 118:9–18.

Sharp, L. A. 2012. Stealth learning: unexpected learning opportunities through games. J. Instr. Res 1:42–48.

Taspinar, B., W. Schmidt, and H. Schuhbauer. 2016. Gamification in education: a board game approach to knowledge acquisition. Procedia Comput. Sci. 99:101–116.

West, S. 2015. How to win at evolution. Nature 528:192.

Zahavi, A., and A. Zahavi. 1999. The handicap principle: a missing piece of Darwin's puzzle. Oxford Univ. Press, Oxford, U.K.

Associate Editor: N. Johnson
Handling Editor: T. Chapman

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supporting Information