ABSTRACT

Teachers are eager for professional development on teaching evolution, especially if it includes direct ties to relevant curricula and detailed lesson plans. Howard Hughes Medical Institute’s BioInteractive Online Professional Learning: Evolution course was developed to provide educators with free, in-depth, multimedia resources that highlight important scientific concepts and studies in evolution and engage participants through interactive activities that link to student resources. Our goals in the development of the asynchronous, nonfacilitated course were to (1) deepen teachers’ content knowledge of evolutionary concepts essential to NGSS and AP Biology courses, (2) increase teachers’ confidence and comfort in teaching evolution content to general biology and AP Biology students, (3) have teachers identify major evolutionary concepts in scientific studies, authentic data, or educational media used to teach evolution, and (4) assist teachers in identifying and incorporating relevant BioInteractive resources to illustrate evolutionary content and science practices in their own course(s). Our results from a postcourse survey that included pre-post retrospective confidence questions suggest that the course improved educators’ knowledge in evolution and their confidence in teaching evolutionary topics. Overall, this course provides educators the opportunity to deepen their content knowledge and obtain exciting, relevant, and reliable resources to use in their classrooms.

Key Words: evolution; professional development; online course.

INTRODUCTION

The BioInteractive Online Professional Learning: Evolution course, first published in 2018 and revised in 2019, is designed to support teachers in deepening their content knowledge in biological evolution and provide them with valuable classroom tools. Understanding biological evolution is essential for biological literacy and supporting teachers in teaching evolution is critical. The course introduces teachers to free, high-quality classroom multimedia resources from BioInteractive that are grounded in the process of science and data and use engaging stories to illustrate scientists’ work and motivations. The online, asynchronous, nonfacilitated course consists of three units, which teachers can take in a prescribed sequence to earn a certificate that can be applied to professional development (PD) hours or a noncertification option in which they can access any lesson of their choosing.

Both the evolution education literature and our firsthand interactions and BioInteractive’s surveys of teachers suggested teachers want a PD course that provides opportunities to learn more about evolution (e.g., Friedrichsen et al., 2016; Sanders & Ngxola, 2009). Evolution was ranked as one of the top three choices among 87 biology content topics by 79% of 57 teachers surveyed by BioInteractive in 2015 at the National Science Teachers Association (NSTA) national conference. However, most science teachers have reported that they are more often given opportunities for generic PD as opposed to science-specific PD, let alone PD on evolution in particular (Luft et al., 2009). Providing access to relevant curricula and detailed lesson plans for teaching evolution is also critical (e.g., Friedrichsen et al., 2016; Griffith & Brem, 2004). The 276 Missouri teachers studied by Friedrichsen and colleagues (2016) reported a lack of good lab activities and supplemental materials as their two biggest obstacles to teaching evolution. Lessons that specifically support students in using the practices of science—such as analyzing and interpreting data, constructing explanations, and engaging in arguing from evidence—may be particularly useful (e.g., Johnson & Lark, 2018). Asynchronous, online PD from a trusted, stable provider like Howard Hughes Medical Institute (HHMI) BioInteractive and grounded in lessons that incorporate actual scientific research and integrate the practices of science is scalable and may help address these PD needs. Out of the 57 high school biology teachers surveyed at NSTA in 2015 by BioInteractive, 54 said they would consider taking an asynchronous course.

Evolution education researchers outline other needs that drove the development of the online course. Prior research suggests teachers would benefit from experiences that help them reflect on and build their content knowledge (e.g., Ha et al., 2015; Kim & Nehm, 2011; Nehm et al., 2009; Nunez et al., 2012). For example, research by Plutzer and colleagues (2020), who administered and analyzed a nationally representative survey to 752 high school biology teachers in 2019 concerning teaching evolution, suggested that 46% of biology teachers did not complete a college course with an
Overview of the Course

Course Content

The teacher learning goals for the course are that by the end of the course, teachers will

- deepen their content knowledge of evolutionary concepts that are essential to NGSS and AP Biology courses;
- increase their confidence and comfort in teaching evolution content to general biology and AP Biology students;
- identify major evolutionary concepts in scientific studies, authentic data, or educational media used to teach evolution; and
- identify and incorporate relevant BioInteractive resources to illustrate evolutionary content and science practices in their own courses.

This course consists of three units, and the total time required for the entire course is estimated to be 15 hours. Unit 1 focuses on the mechanisms of evolution. It includes how to build an explanation based on evidence for natural selection. Unit 2 focuses on sources of evidence supporting evolutionary theory, including fossils, anatomy, biochemistry, genetics, and cell biology. Unit 3 focuses on patterns of evolution, including phylogenies and macroevolution. The units are divided into varying numbers of lessons (see Supplemental Data, Table S1, available with the online version of this article). Each lesson includes informational readings and videos and provides activities for participants to apply what they learn.

Design Principles

Although much remains to be learned about effective science PD, especially about biological evolution and online PD, we considered the following PD design features generally recommended by education researchers (e.g., Desimone, 2009; Ha & Nehm, 2015; Wilson, 2013) that are attainable in an asynchronous, nonfacilitated course. (1) Participants should engage as active learners with the course content. (2) The content of the course should be relevant to participants and the learners they teach. (3) Similarly, participants should be given a chance to reflect on the content as both learners and teachers, especially how the content can be incorporated into their specific context. (4) The content should be coherent with standards, in this case aspects of evolutionary biology that are a part of the Next Generation Science Standards (NGSS) and AP Biology, and teachers should reflect on how the content ties to the standards. The content is also relevant for teachers of International Baccalaureate Biology, honors biology, or middle school biology. Although we could not assure other recommended features (collective participation or activities and reflection of sufficient duration), it is possible to use the course to align with those features too. For example, during the 2018–2019 school year, 18 teachers in Math for America participated in the online course together over a four-month period where they met monthly. In these meetings, teachers reflected as a group on their implementation of the activities and presented on a lesson from the course that they used with their students, including the modifications they made to best suit their student population. We encourage course exploration as a community to enhance learning through interacting with peers and gaining insights from one another (Hord, 2004; Spillane & Louis, 2002).

We designed the course with features for effective science PD by including activities that are closely aligned to teachers’ practice, immersing teachers in inquiry experiences and ensuring that curriculum materials are educative for teachers and transferable to their students. We also included instruction on specific teaching innovations, in this case integrating science practices and evolutionary biology content (Wilson, 2013). A final recommendation from the literature is taking participants’ physical and psychological comfort into account. This was accomplished by making the course online, asynchronous, and free.

Course Features

Interactive, engaging media. BioInteractive hosts a large range of high-quality short films, virtual labs, and online interactions grounded in contemporary science and field-tested in the classroom. Selected segments from the short films and activities are implemented throughout the course with follow-up questions and tasks for adult learners. For example, teachers use a modified version of BioInteractive’s Lizard Evolution Virtual Lab to investigate how anole lizard populations change over time in response to different environments. They are given a scenario in which lizards from a relatively large island with varied vegetation and large trees are placed on islands that lack lizards and have only small bushes and grass.

Teachers first describe the variation in leg and body length in the large island lizard population with a “virtual ruler” that allows them to measure these characteristics on X-rays from anoles used in the actual research study (Figure 1). Measuring these traits allows teachers to actively participate in data collection. Teachers determine the ratio of hind-limb length to body length, and the resulting sample data is subjected to statistical analysis. Videos and slides display step-by-step instructions on how the sample mean, standard deviation, standard error of the mean, and 95% confidence intervals are calculated. Later on, the traits of lizards from the experimental islands are compared to those on the larger island to investigate
whether or not the lizards on the experimental islands adapted. Measuring, data analysis, and guided mathematical calculations reinforce scientific reasoning and help teachers to learn and integrate these science practices.

Direct links to related student activities or resources. To help teachers link their learning about evolutionary concepts with resources and activities to use with their students, teachers use some of the same interactives as students. One example is the interactive tool EarthViewer, which is an application that allows learners to navigate, visualize, and learn about the changes in Earth’s long geological history (Figure 2). Numerous factors can be traced across time, including atmospheric composition, global temperature, biodiversity, day length, solar luminosity, and the location of modern-day cities. Optional links to other related BioInteractive materials are provided at the bottom of each course page; in this case EarthViewer is linked to an additional resource, “Making of Mass Extinctions.”

End of lesson review quizzes and end of unit test. Research suggests that frequent assessments improve learning and retention of content (Roediger & Karpicke, 2006). To help provide formative and summative feedback, at the end of each lesson teachers respond to 4–7 review questions, and at the end of the unit they complete a 15-question test. Teachers need to receive at least an 80% on an assessment to proceed to the next lesson or unit in the certificate version of the course.

Deeper Content Dives. Deeper Content Dives are offered to further investigate and strengthen teachers’ knowledge in the subject matter explored within the particular lesson. When investigating the origin of genetic variation for inherited traits, a link to a Deeper Content Dive leads to a video describing how color vision evolved in the lineage that led to modern humans (Figure 3).

Educator Tips. Similar to the Deeper Content Dives, Educator Tips are additional resources to provide teachers with implementation tips for BioInteractive activities. These are created by educators showcasing how they use the resources within their own classrooms. The majority of Educator Tips also include videos with the educator and visual aids to explain how they use the resource. These also include links to the resource and associated worksheets, instructions, and additional information so that educators can easily implement the content in their classroom.

Certificate or noncertificate version. The BioInteractive survey at NSTA in 2015 suggested that some teachers wanted to take an online course to help them meet requirements for PD hours. To accommodate those needs, a certificate version of the course is available. Teachers can receive one certificate after completing Unit 1, which is estimated to require at least 10 hours. Teachers can receive another certificate after completing both Units 2 and 3, which together are estimated to require at least 5 hours. Teachers can complete the two segments independently. On the other hand, some teachers wanted to access portions of the course materials “just in time,” and some wanted to use portions of the course with their own students. To accommodate those needs, a noncertificate version.

Full-Color Vision: A Result of Gene Duplication?
How did a gene duplication event result in full-color vision?
Nonhuman primates are red/green color blind, and likely so were our primate ancestors. How did our lineage evolve color vision? Gene duplication seems to be the answer. Watch the following video to learn more.

Visit the BioInteractive website for related resources.

Explore Your Inner Animals

Figure 1. Screenshot from the Lizard Evolution Virtual Lab showing how users measure phenotypes in anole X-rays.

Figure 2. BioInteractive’s EarthViewer, featuring the Paleo Earth timeline on the left (with other timelines available).

Figure 3. Screenshot of an interactive resource provided in a Deeper Content Dive regarding inheritance. Users are able to watch a video describing gene duplication in the lineage that led to humans, leading to color vision.
version of the course is available that allows teachers to access all the lessons as needed.

○ Evaluation of the Course

To gain insights into how well the course supported teachers in meeting the course learning goals and to inform revisions of the course (updated in October 2019) and the development of future BioInteractive professional learning courses, we asked teachers of the first version of the course to complete a postcourse survey after completing Unit 1 and separately after completing both Units 2 and 3. The survey included pre-post retrospective confidence questions because we wanted to better understand subjective changes experienced by course participants (Hill & Betz, 2005). In other words, we wanted to learn how teachers felt about the effectiveness of the course and how it affected their growth in knowledge and skill development. We formally tested statistical hypotheses about changes in means between teachers’ self-reported confidence before and after the course using two-tailed, paired t-tests and computed Cohen’s d values for each comparison of means.

The evaluated version of the course used an electronic notebook and was only available in the certificate (prescribed sequence) version. A total of 92 participants completed the survey for Unit 1, and 69 completed the survey for Units 2 and 3.

○ What We Learned

Overall, the large majority of teachers responded positively to the online course. When asked if the course met their expectations, 91% of the teachers completing Unit 1 agreed, as did 96% of the teachers completing Units 2 and 3. When asked if they planned to implement the lessons with their students, 94% of teachers completing Unit 1 said “yes” as did 91% of teachers completing Units 2 and 3. Analysis of open-ended questions in the survey suggests that teachers appreciated the embedded media, especially short video clips; the student lessons provided within the context of the PD lessons; the clarity of the evidence for evolution case studies; and the inclusion of data from actual studies. Paired-samples t-tests conducted to compare the changes in means between teachers’ self-reported confidence before and after the course all showed highly significant increases in confidence ($p < 0.0001$) with medium to large effect sizes, ranging from $d = 0.60$ to 1.32. We will describe the results of the evaluation in light of the teacher learning objectives, beginning each section with representative quotes from post surveys that personify the quantitative results. Tables summarizing all the postsurvey responses from teachers completing Unit 1 and Units 2 and 3 are included in Table 1 and Supplemental Data (Tables S2–S4, online).

**Goal 1: Deepen content knowledge of evolutionary concepts that are essential to NGSS and AP Biology courses.**

“This was an unbelievable experience! I loved every bit of it. It makes the study of evolution so clear…. If teachers today taught evolution the way you did in this course …. everyone would totally understand it. This was a fun course in which I felt I was a scientist actually doing the investigations and learning evolution at the same time.”

“This course allowed me to act and study like a scientist. This was amazing in being able to see actual evidence of organisms undergoing evolution. It really gave a clear and concise picture of what evolution is all about.”

In response to general survey questions (see Supplemental Data, Table S2, online), 95% of teachers, on average, agreed or strongly agreed that the course deepened their understanding of evolution and that the course assignments provided useful opportunities for them to strengthen their knowledge. Additionally, pre-post retrospective survey questions about teachers’ confidence in their understanding of key concepts from each unit showed that there was a significant and substantial increase in the percentage of users that were moderate to highly confident. At the end of Unit 1, 94% of teachers were moderately to highly confident in their content knowledge from the unit (see Supplemental Data, Table S3), as were 97% of teachers at the end of Units 2 and 3 (see Supplemental Data, Table S4). The largest gains in confidence in Unit 1 were for calculating descriptive statistics that explain variation in populations (a learning outcome that aligns with the science practices of analyzing and interpreting data and of using mathematics, as well as standards in the Common Core), for describing the similarities and differences among four mechanisms of evolution, and for using evidence to relate the strength of selection to the rate of change in phenotypes in a population over time. After Units 2 and 3, teacher confidence in their content knowledge had the largest gains in using evidence to reconstruct phylogenetic relationships and explaining how different definitions of species affect how biologists study speciation. Again, many of the learning gains are in areas highly integrated with science practices.

**Goal 2: Increase confidence and comfort in teaching evolution content to general biology and AP Biology students.**

“This is not my field of expertise, so I am very appreciative that this course gave me a lot more confidence than I had before I took it. I also took it to find more resources for my students which I got and am looking forward to using.”

Table 1 summarizes important gains in teachers’ confidence in teaching evolution both at the general high school levels and at advanced levels. The percentage of teachers that are highly confident in their ability to teach general biology increased by 30% after Unit 1 and 32% after Unit 2. Teacher’s confidence in teaching evolution at an advanced college level also grew substantially, with the percentage of teachers reporting high confidence increasing by 29% after Unit 1 and after Units 2 and 3.

**Goal 3: Identify major evolutionary concepts in scientific studies, authentic data, or educational media used to teach evolution.**

“For me, this course was …. about getting new ideas regarding resources, how to better sequence materials, how to ask more engaging/clear questions, and how to better collect and use data in my classroom. This course was super helpful in all of these ways, and I really appreciate having free and excellent PD in this area.”

The success of this goal can best be seen in Table 1, in which the percentage of teachers reporting moderate to high confidence in their ability to utilize authentic scientific data was 90% after Unit 1 (an increase of 46% compared to their confidence before the course) and 96% after Units 2 and 3 (an increase of 33%).
Goal 4: Identify and incorporate relevant BioInteractive resources to illustrate evolutionary content and science practices in teachers’ own course(s).

“I hoped to learn new material and get new ways to teach my students and I got exactly that. I was hoping to be inspired to try some new things in the classroom and I was!!”

“This was totally amazing. This helped me see how I can get my students involved in acting like a scientist by using real world applications without having to go to the Galapagos Islands, etc. I was totally engaged and excited throughout this entire course. I can’t wait to show my students these great activities.”

Nearly all teachers (96%) agreed or strongly agreed that they were introduced to instructional resources from HHMI BioInteractive and plan to integrate these resources into the classroom. Additionally, Table 1 shows significant increases in educator’s confidence in utilizing BioInteractive resources to scaffold scientific practices and to teach students evolution content. For scaffolding science practices, the percentage that reported moderate to high confidence increased from 41% to 88% after Unit 1 and from 54% to 94% after Units 2 and 3. Similarly, for using BioInteractive resources to teach students evolution content, the percentages reporting moderate to high confidence increased from 59% to 94% of teachers for Unit 1 and from 64% to 97% for Units 2 and 3.

### Changes to the Course Based on the Evaluation

#### Time Estimates

A beta version of the course was piloted with six teachers who completed all three units. Results from the pilot test led to the removal of some content and was the basis for an initial estimate of the time needed to complete each unit which was initially five hours for Unit 1 and five hours for both Units 2 and 3. However, among the pilot teachers there was wide variation in the time commitment needed for the course. Analysis of open-ended feedback from some teachers in the evaluation suggested they needed more time for Unit 1 and we increased the estimated time for Unit 1 to 10 hours.

#### Notebook

In the initial launch of the course, we included an electronic notebook that participants used to answer reflection and extension questions on the course content and teaching the content to students.

### Table 1. Summary and analysis of teacher overall pre-post retrospective confidence by units. The mean was derived by converting the Likert scale into numerical values (1 = no confidence, 2 = slight confidence, 3 = moderate confidence, and 4 = high confidence).

| General Confidence Questions | No Confidence % | Slight % | Moderate % | High % | Mean | Std. Dev | Cohen's d |
|-----------------------------|----------------|---------|------------|-------|------|---------|-----------|
| Teaching evolution to regular high school biology students | | | | | | | |
| Unit 1 | Pre | 3.3 | 12.0 | 37.0 | 47.8 | 3.29 | 0.81 | 0.60 |
| | Post | 1.1 | 4.3 | 16.3 | 78.3 | 3.72 | 0.60 |
| Units 2 & 3 | Pre | 2.9 | 10.1 | 37.7 | 49.3 | 3.33 | 0.78 | 0.69 |
| | Post | 0.0 | 2.9 | 15.9 | 81.2 | 3.78 | 0.48 |
| Teaching evolution at an advanced level (e.g., AP Biology) | | | | | | | |
| Unit 1 | Pre | 9.8 | 26.1 | 43.5 | 20.7 | 2.75 | 0.90 | 0.72 |
| | Post | 5.4 | 3.3 | 41.3 | 50.0 | 3.36 | 0.79 |
| Units 2 & 3 | Pre | 7.2 | 20.3 | 47.8 | 24.6 | 2.90 | 0.86 | 0.68 |
| | Post | 1.4 | 7.2 | 37.7 | 53.6 | 3.43 | 0.70 |
| Assigning authentic scientific data to students to support learning objectives in evolution | | | | | | | |
| Unit 1 | Pre | 7.6 | 47.8 | 35.9 | 8.7 | 2.46 | 0.76 | 1.32 |
| | Post | 1.1 | 7.6 | 40.2 | 51.1 | 3.41 | 0.68 |
| Units 2 & 3 | Pre | 5.8 | 31.9 | 44.9 | 17.4 | 2.74 | 0.82 |
| | Post | 0.0 | 4.3 | 43.5 | 52.2 | 3.48 | 0.58 |
| Using HHMI BioInteractive resources with students to scaffold scientific practices | | | | | | | |
| Unit 1 | Pre | 17.4 | 41.3 | 28.3 | 13.0 | 2.37 | 0.92 | 1.13 |
| | Post | 1.1 | 10.9 | 44.6 | 43.5 | 3.30 | 0.71 |
| Units 2 & 3 | Pre | 11.6 | 34.8 | 42.0 | 11.6 | 2.54 | 0.85 |
| | Post | 0.0 | 5.8 | 43.5 | 50.7 | 3.45 | 0.61 |
| Using HHMI BioInteractive resources to teach students evolution content | | | | | | | |
| Unit 1 | Pre | 12.0 | 28.3 | 46.7 | 13.0 | 2.61 | 0.86 | 1.18 |
| | Post | 1.1 | 5.4 | 34.8 | 58.7 | 3.51 | 0.65 |
| Units 2 & 3 | Pre | 8.7 | 27.5 | 50.7 | 13.0 | 2.68 | 0.81 |
| | Post | 0.0 | 2.9 | 34.8 | 62.3 | 3.59 | 0.55 |
For longer assignments with many graphics, they downloaded and completed individual journal worksheets. Feedback from the evaluation suggested that these options were cumbersome, so in the updated version of the course, we combined the notebook and worksheets into a single comprehensive workbook for each unit available as fillable PDFs. Follow-up discussions with participants suggested the fillable PDFs were easier to develop than the original artifact-collection method and was easier to use.

○ Comparison to Other Research on Online Professional Development

Research on online PD is developing, though more studies are needed to cover this growing area and its diversity of formats. Similar to the results of the evaluation of our course, other researchers have found that many teachers generally have positive experiences with online PD (e.g., Parsons et al. 2019; Yoon et al., 2020). Surveys and evaluations suggest teachers prefer online PD, especially if it is not required, because it is more convenient than other forms of PD; the materials are accessible anytime, including “just in time”; they can apply what they learn to their own practice; and it is noncompetitive, which supports stronger learning environments (Nelson, 2019). Some rigorously designed studies suggest that online PD can be just as effective or even more effective than more expensive face-to-face PD (e.g., Fishman et al., 2013; Kissau, 2015; Yoon et al., 2020), from teachers’ perceptions of their learning and studies on student learning. This work is important because online PD affords the scale needed to impact a nation of teachers.

○ Summary

We recognize that teachers are the most important investment for increasing students’ understanding of evolution and the science practices that serve as the basis for generating and interpreting the evidence for this overarching framework for biology. So far, over 2200 learners have engaged with the course. Our hope is that the BioInteractive Online Professional Learning: Evolution course continues to grow teachers’ confidence in understanding and teaching evolution and provides useful resources to make their lives easier and help student learn these vital concepts. We welcome feedback to continue to improve the online PD course and for future offerings.

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