BUILDING AN UNDERSTANDING OF EVOLUTION: AN ONLINE RESOURCE FOR TEACHING AND LEARNING

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ABSTRACT. The Understanding Evolution website (http://evolution.berkeley.edu/) was developed to provide a freely accessible resource that promotes the teaching of evolution and improved understandings of evolution among students and the general public. Evaluations show that the strategies employed in site design have allowed it to effectively meet those goals, while maintaining a practical and scientific perspective on this topic and remaining disentangled from the "controversy" related to evolution in the public sphere.

DÉVELOPPER UNE COMPRÉHENSION DE L'ÉVOLUTION :
UNE RESSOURCE EN LIGNE POUR L'ENSEIGNEMENT ET L'APPRENTISSAGE

RÉSUMÉ. Le site Web Understanding Evolution (http://evolution.berkeley.edu/) a été créé dans le but d'offrir une ressource accessible et gratuite qui fait la promotion de l'enseignement de l'évolution et tente de mieux faire comprendre celle-ci auprès des étudiants et du public en général. Des évaluations indiquent que les stratégies employées dans la conception du site ont permis d'atteindre efficacement ces objectifs, tout en maintenant une perspective pratique et scientifique sur ce sujet et en se tenant loin de la « controverse » liée à l'évolution au sein de la population.

INTRODUCTION

Understanding Evolution (UE, http://evolution.berkeley.edu/) is a multi-audience website with two major components that deliver accessible information on evolution to K-12 science teachers, their students, and the general public. UE was developed in two phases: phase one targeted K-12 teachers and was funded by the National Science Foundation; phase two expanded the resource to multiple audiences and was funded by the Howard Hughes Medical Institute. The site provides opportunities for rich and robust explorations of topics in evolutionary biology, leading to better understandings of evolution and how it impacts our lives.

The first phase of the project focused on serving K-12 teachers, with the goal of improving both teacher understanding of evolution and their confidence to teach evolution. Importantly, the teacher's component (Figure 2) also

provides resources for teaching: clarification of common misconceptions, a conceptual framework, a searchable database of more than 100 vetted lessons, and strategies to overcome roadblocks to teaching evolution. Phase two produced a second site component with additional features targeting students and the public (Figure 3). New features include interactive content modules for different audiences, in-depth student investigations, exemplars of evolution, a comic strip, research profiles, FAQs on the "controversy" surrounding evolution, and a monthly news brief entitled *Evo in the News*.

RATIONALE FOR BUILDING *UNDERSTANDING EVOLUTION*

Evolution affects many aspects of our lives and is the central organizing principle that biologists use to understand the world. Nevertheless, the poor state of Americans' understanding and acceptance of this concept is well documented. Polls continue to show strong differences between the public's acceptance and understanding of evolution and that of the scientific community. The latter sees evolutionary theory as extremely well supported and non-controversial, while a sizable segment of American society has little understanding of evolution and rejects it as a valid explanation for the diversity of life (Rutledge & Warden, 2006). Furthermore, students at grade levels in which they are expected to grasp the basics of evolution (middle school through university-level) demonstrate significant misconceptions and misunderstandings of evolutionary processes (e.g., Beardsley, 2004; Demastes, Settlage, & Good, 1995; Jenson & Finley, 1995).

Clearly, the disconnects between the scientific community's and the broader public's understandings of evolution are not being sufficiently remedied within the classroom; however, the causes of this lack of remediation are multiple and complex. The presence of evolution in the teaching standards is important but does not necessarily mean that evolution is taught well. Many teachers avoid teaching evolution so as to avoid the accompanying controversy (Rutledge & Mitchell, 2002). Perhaps worse, a significant number of teachers do not fully accept evolutionary theory and therefore do not teach it well, do not teach it at all, or teach it along with creationism or Intelligent Design, creationism's latest guise (Eve & Harold, 1991; Scott, 1999). Finally, many teachers are simply not prepared to teach evolution. It has been argued that evolution is particularly challenging because it relies on emergent processes, about which students are likely to maintain robust misconceptions (Chi, 2005). Teaching such topics would be significantly aided by the availability of high-quality teaching resources. However, in 2000, before UE, few if any comprehensive resource packages were available for science teachers that addressed evolution in terms of both content and pedagogy. This paucity and the urgent need for such resources were reinforced by the findings of the National Conference on the Teaching of Evolution

(2000), which brought together representatives from scientific, educational, and other professional organizations to improve the quality and accessibility of materials that support the teaching of evolution. UE was constructed to meet teachers' needs identified at that conference.

CONSTRUCTION OF THE SITE

In building this site, we took a highly collaborative approach, enlisting the participation of the major stakeholders: scientists (who want to see their science accurately communicated), defenders of evolution (such as the National Center for Science Education, who want to support accurate teaching of science), and teachers (who want an easy-to-use product that strengthens their own science content knowledge and provides effective teaching resources). Several representatives from each of these stake-holding groups were recruited at the start to guide content selection and site design. In addition, we employed a web team composed of a programmer and graphic artists. One of the keys to the success of this approach was the involvement of all parties during all stages of development. This ensured an opportunity for open communication, multiple perspectives, and learning from the expertise of others. On a practical basis this also meant fewer errors and less time wasted mistakenly focusing on technically infeasible or pedagogically ineffectual efforts.

Involving teachers in the content selection and design of the teacher's component was critically important in developing a product to meet the needs of that audience. However, the population of teachers targeted by the site is a large and diverse group that would be difficult to fully represent on any advisory panel. Thus, to ensure that the needs of this wider audience were met, we informally surveyed approximately 40 California science teachers via email and conducted sessions regarding teachers' needs at the National Conference on the Teaching of Evolution (2000). Those efforts identified several explanations for the less-than-ideal state of evolution instruction in the U.S.: (1) teachers feel that they cannot teach evolution because they lack the necessary content knowledge and resources, (2) others teach evolution but could do a better job with more resources, (3) some have difficulties because their district does not support evolution instruction, and (4) some are hesitant or frightened about teaching evolution. Based on these results, it was concluded that UE should be constructed (1) to provide teachers with up-to-date, authentic, stimulating content for their classes, and (2) to increase confidence levels in teaching evolution.

Construction of the teacher's component was also guided by several theoretically-rooted design considerations. These fall into two general categories: how to teach teachers and how to teach K-12 students.

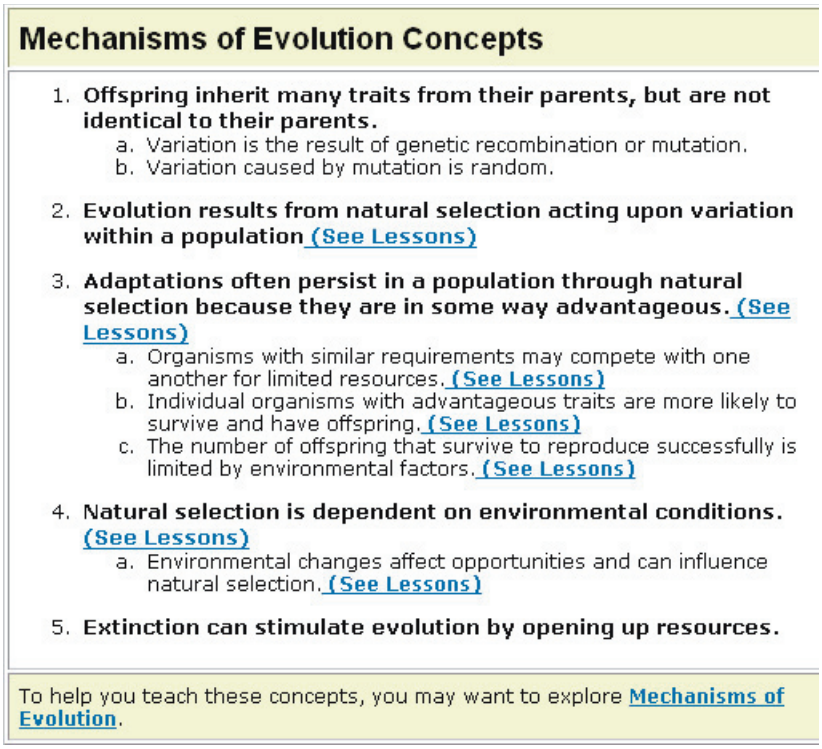
Teaching teachers

The initial target audience for this site was practicing and pre-service teachers. As learners, this audience has special needs and characteristics. Huang (2002) reviews the literature on adult learners and identifies adults (and hence, teachers) as particularly motivated learners when the knowledge to be gained will help the learner deal with problems in his or her life. Thus, teachers will be motivated to learn about evolution if it is clear how that knowledge will help them in their classrooms. We would expect teachers to be looking for information on evolution that applies to the development and teaching of curricular materials – content, learning objectives, and lessons plans that will directly assist them with their classroom teaching.

Similar conclusions are supported by recent educational research emphasizing "authentic" instruction (e.g., Newmann & Wehlage, 1993), which suggests that teaching and assessment should be rooted in the actual practices and situations in which learners are expected to apply their knowledge. Although these arguments are generally used to identify strategies for use by K-12 teachers in their classrooms, they also have implications for professional development (Rasku-Puttonen, Etelapelto, Lehtonen, Nummila, & Hakkinen, 2004). In terms of teacher professional development, the term "authenticity" suggests professional development that is rooted in the practices and constraints of classroom teaching.

Based on the above theoretical considerations, as well as our interviews and consultation with teachers, we built several tools into UE that were designed to improve efficiency and authenticity. A large set of classroom-tested and science-vetted lessons is accessible from a fully searchable lesson database. Our "Teach This" links enable a user studying a particular topic to immediately access a set of selected classroom lessons designed to teach that particular topic. A conceptual framework (Figure 1) for organizing instruction on the topic of evolution across different grade spans is also keyed directly to appropriate lessons. Simple and practical teaching tips (such as why "design-an-animal" activities are best avoided) are also provided. Finally, several design elements of the site are intended to improve authenticity for teachers. For example, *Quick Quizzes* (self-assessments at the end of content sections) come in the form of a class of hypothetical students challenging the user with the difficult questions that come up in real-life classrooms.

Another characteristic of adult learners (and hence, teachers) noted by Huang (2002) is the primacy of time constraints in their concerns and the need for self-direction and autonomy. In UE, we responded to this need through the use of technology. Creating UE as an online resource allows teachers a maximum amount of contact with sources of information and the autonomy of an independent study mode of instruction. Asynchronous learning accommodates individual schedules and encourages time to reflect.



Mechanisms of Evolution Concepts

1. **Offspring inherit many traits from their parents, but are not identical to their parents.**
   a. Variation is the result of genetic recombination or mutation.
   b. Variation caused by mutation is random.
2. **Evolution results from natural selection acting upon variation within a population** (See Lessons)
3. **Adaptations often persist in a population through natural selection because they are in some way advantageous.** (See Lessons)
   a. Organisms with similar requirements may compete with one another for limited resources. (See Lessons)
   b. Individual organisms with advantageous traits are more likely to survive and have offspring. (See Lessons)
   c. The number of offspring that survive to reproduce successfully is limited by environmental factors. (See Lessons)
4. **Natural selection is dependent on environmental conditions.** (See Lessons)
   a. Environmental changes affect opportunities and can influence natural selection. (See Lessons)
5. **Extinction can stimulate evolution by opening up resources.**

To help you teach these concepts, you may want to explore Mechanisms of Evolution.

FIGURE 1. Excerpt from middle school level conceptual framework

The use of selected external links provides the user with access to a huge array of supplemental resources. Another characteristic of adult learners (and hence, teachers) noted by Huang (2002) is the primacy of time constraints in their concerns and the need for self-direction and autonomy. In UE, we responded to this need through the use of technology. Creating UE as an online resource allows teachers a maximum amount of contact with sources of information and the autonomy of an independent study mode of instruction. Asynchronous learning accommodates individual schedules and encourages time to reflect. The use of selected external links provides the user with access to a huge array of supplemental resources.

Teaching K-12 students

The ultimate aim of UE is to improve not just teachers' understandings of evolution, but also those of their students. This was facilitated by employing specific pedagogical models and strategies for enhancing student learning.

First, content selection for UE was based on an "iceberg" model of teacher knowledge, which suggests that good pedagogy requires teachers to have a great deal of information and understanding *below the surface* that may never be communicated to students. From a deep understanding of evolutionary biology, teachers can select different kinds and levels of information to develop effective curricula and gain confidence in communicating the ideas of evolution. Thus, content provided by the site extends to a much deeper level than we expect will be conveyed to students.

Second, many educational researchers agree on the importance of being aware that students come into the classroom with vast conceptual ecologies of their own (e.g., Clement, Brown, & Zietsman, 1989; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992). It is essential for teachers to have an understanding of what prior knowledge (correct and incorrect) a student is likely to have regarding particular content. UE's *Misconceptions* section is based upon this perspective. It outlines incorrect but tenacious and appealing ideas that students (and many members of the lay public) are likely to hold (e.g., that organisms must "try" to adapt). These misconceptions were identified based upon the experiences of our advisory board and upon the education and social science literature (e.g., Alters & Alters, 2001; Bishop & Anderson, 1990).

Third, the site advocates what we think of as concept-based teaching (related to teaching for conceptual change; e.g., Scott, Asoko, & Driver, 1992). This is the seemingly obvious, but nevertheless infrequently employed, practice of organizing teaching around specific concepts that students should learn. This means selecting focal concepts that are powerful, generative, and important, that are developmentally appropriate, that anticipate later learning and elaboration, and that build upon and reinforce one another in meaningful ways. With this approach, assessment becomes more straightforward and authentic, applying the gold standard of students being able to use a targeted concept in a novel situation. These ideas form the root of UE's conceptual framework (Figure 1). For example, at a fundamental level, the concept of natural or artificial selection can be broken down into *Variation*, *Inheritance*, and *Selection*, repeated over a great deal of *Time* (VIST). Even though the concept of natural selection (that "evolution results from selection acting upon genetic variation within a population") is appropriate material for grades 9-12, the components of this idea (that "there is variation within a population," that "offspring inherit many traits from their parents," that "advantageous features help living things survive," and that "life has been on Earth for a long time") are appropriate for earlier grades and can build a foundation for a full understanding of evolution later on.

Finally, we recognize that a variety of pedagogical strategies are appropriate in different settings, for different teachers, and with different learners.

Therefore, we did not restrict the lessons selected for the lesson database to a single teaching style or lesson framework (e.g., the "5 Es" model, Engage, Explore, Explain, Elaborate, and Evaluate, or problem-based learning; Bybee, 1997; Gallagher, Sher, Stepien, & Workman, 1995) – although many of the lessons are flexible enough to be modified to fit that or other frameworks. All of our lessons were either selected by a diverse panel of master teachers for pedagogical soundness and by science advisors for scientific accuracy or were developed by those same individuals specifically for UE.

PROJECT DESCRIPTION

The teacher audience

The homepage design of the teacher's component (Figure 2) reflects both the substance of the site and its development. Rather than focusing on the "controversy" of evolution, the page depicts a cladogram, with one lineage (labeled *Learning Evolution*) providing an array of resources that communicate the science of evolution and with a second lineage (labeled *Teaching Evolution*) providing resources for effective teaching of the topic.

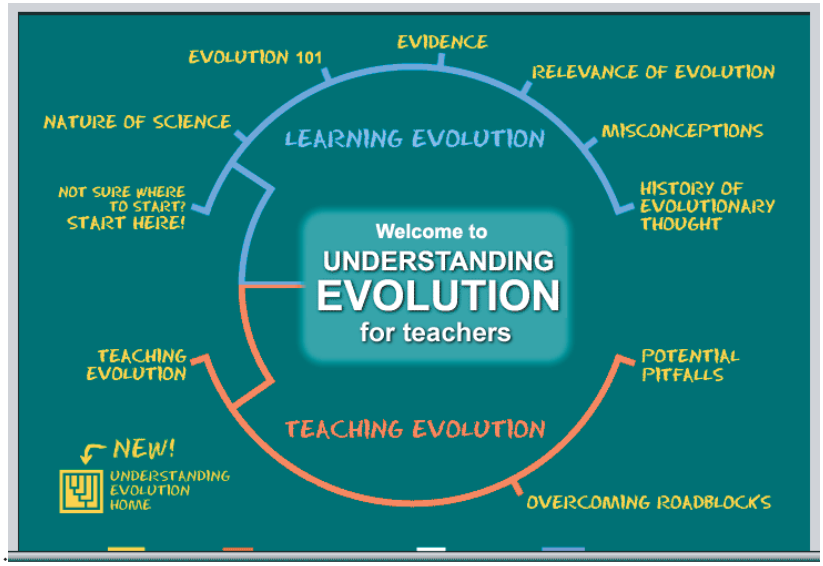


FIGURE 2. The homepage of the UE teacher's site component (http://evolution.berkeley.edu/evosite/evohome.html)

As described in *Construction* above, prior to the start of this project, we spent considerable effort identifying the needs of K-12 teachers and the resources available to them that support the teaching of evolution. Finding a void, we focused on providing information covering what content teachers needed

and wanted to know, what skills they needed, and what classroom resources would be helpful to support their teaching. These needs are reflected in the array of resources available on the teacher's site component (see Table 1).

TABLE 1. Summary of resources available on the UE teacher's component

Evolution content
Nature of science: the basic premises of scientific questions and methods
Evolution 101: nuts-and-bolts information on evolutionary mechanisms, patterns, and other details
Lines of evidence: summary of the evidence supporting evolutionary theory
Relevance: a look at how evolution affects our lives today
Misconceptions: a list of common misconceptions about evolution along with clear explanations of them
History of evolutionary thought: key people, ideas, and research in the history of evolutionary thought
Teaching resources
Teaching evolution: searchable lesson database, conceptual framework, and teaching philosophy – all related to teaching evolution
Overcoming roadblocks: a guide to identifying and dealing with potential obstacles to the teaching of evolution
Potential pitfalls: list of teaching tips to avoid causing student confusion

There are two structural elements unique to the teacher's component worthy of additional comment: the conceptual framework and the searchable lesson database. The conceptual framework (Figure 1) allows teachers to organize objectives for student learning into a coherent, grade-level-appropriate agenda that effectively builds upon student knowledge gained in previous classes. To facilitate use in multiple classroom settings and to align best with different state science standards, the framework is divided into five themes: *History*

of life, *Evidence of evolution*, *Mechanisms of evolution*, *Nature of science*, and *Evolution and the nature of science*. This framework was developed by a team of teachers and scientists making use of resources such as the *Atlas of Science Literacy*, *Benchmarks of Science Literacy*, and the *National Science Education Standards*. However, the framework goes beyond these resources by providing for reinforcement of concepts learned at previous grade levels and by linking concepts directly to appropriate teaching resources.

The searchable lesson database includes over 100 resources for classroom use. All resources have been vetted for both scientific accuracy and for pedagogy. Teachers can search by concept, topic, keyword, and/or grade level to identify appropriate online lessons, tutorials, investigations, interviews, and student readers. A standard template for each resource lets teachers prescreen items by providing a summary, a list of concepts addressed by the resource, grade level appropriateness, estimated time to complete, links to suitable teacher background information, and teaching tips. This database continues to grow as more resources are developed or are submitted and evaluated for inclusion.

An expanded audience

Early on in the project, it became apparent that the user base of the site was broader than just K-12 teachers. Webmaster comments and web log analysis indicated use throughout Europe, Central and South America, Canada, Singapore, Japan, Australia, and New Zealand, with requests for translation into Spanish, Portuguese, and Turkish. UE content was (and still is) being used by middle and high school students, as a course supplement for undergraduates in several U.S. universities, for docent training at several museums and science centers, and as the primary content source for an online teacher professional development course offered by Montana State University. The site was also used in presentations to the Boards of Education in Ohio and Minnesota during discussions about teaching evolution in their public schools.

With additional funding, we were able to respond to this expanded audience by "re-packaging" much of the teacher material into formats suitable for different audiences and by building entirely new resources for these audiences. These resources are available on a site component targeting the general public and students (Figure 3). Whereas information for teachers may contain suggestions for use in the classroom, links to grade-level-appropriate activities, and a list of discussion questions, the same material for the general public is formatted to begin with a set of overarching questions addressed by the article and closes with links to additional articles that might be of interest to the reader.

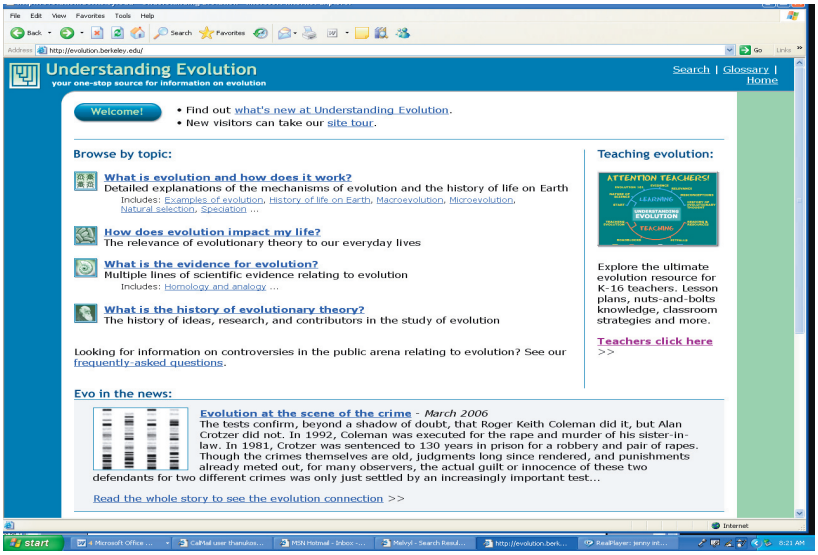


FIGURE 3. The homepage of the UE student and general public site component (http://evolution.berkeley.edu/).

This new component contains a wealth of feature articles written for both a general audience and for targeted audiences, such as middle and high school students. Visitors are able to search by keyword or topic, or they may browse the content organized into four focal areas:

- What is evolution and how does it work? – Detailed explanations of the mechanisms of evolution and the history of life on Earth
- How does evolution impact my life? – The relevance of evolutionary theory to our everyday lives
- What is the evidence for evolution? – Multiple lines of scientific evidence relating to evolution
- What is the history of evolutionary theory? – The history of ideas, research, and contributors in the study of evolution

Resources available run the gamut from highly youth-oriented (such as the comic *Survival of the Sneakiest*), to student-specific (such as the interactive lab on arthropod evolution), to advanced articles for adult learners (such as an article on endosymbiosis and the origins of eukaryotes). The browsable resource library also includes links to a small set of carefully selected resources from other organizations, such as PBS's *Origins of Humankind* and ActionBioscience's interview with Douglas Futuyma.

Two of the site's feature types are noteworthy for their ability to integrate the nature of science with the relevance of evolution. Research profiles are short articles that focus on the research of a single individual in order to communicate the nature of science as a human endeavor and the relevance of evolution to people's lives. They have four key components:

- The researcher – The personal side of doing science, scientists' histories and anecdotes
- The research application – The story of how the science was done, the initial questions, observations, hypotheses, testing methods, and analysis
- The relevance – The broader impact of the research in the form of a contribution to other research areas and/or relevance to society
- The evolution – The basic concepts in evolution that the research depends upon, thus reinforcing topics discussed throughout the rest of the site

Another feature of the site, *Evo in the news*, lets teachers, students, and the public keep up with the frontiers of evolutionary biology by providing monthly updates on evolutionary research that is making headlines and that demonstrates the relevance of evolution to our lives. These updates highlight evolution in places both unexpected (e.g., DNA fingerprinting, genetically-modified foods) and topical (e.g., SARS, the avian flu).

The homepage changes monthly with new installments of *Evo in the News*, new research profiles, and other new resources. Because the content is constantly growing, we have initiated a subscription service for individuals (especially teachers) who would like to receive automated emails when new content and resources are added to the site. This service encourages teachers to regularly revisit the topic of evolution throughout the year and alerts them to advances in the field.

SITE EVALUATION

An extensive, multi-component evaluation of UE was performed by Rockman *ET AL* (REA), an independent evaluation group with expertise in educational technology interventions, in order to determine how the site was being used at the K-12 level. Over the course of the twelve evaluation components, which included online surveys, think aloud protocols, pre/post-tests, phone interviews, and website log file analyses, many aspects of the site were assessed, including use, design, navigation, appeal, content quality, user-friendliness, tone, and learning. The results of those evaluations suggest that UE is valued by educators as a comprehensive and exceptionally useful source of clear, accurate information on evolutionary concepts and related topics. The data also indicate that the site provides a wealth of engaging lessons that expand educators' repertoire of strategies for teaching evolution, equipping them

to teach evolution in a hands-on, inquiry-oriented way. A comprehensive summary of these results is beyond the scope of this report, but is available at http://evolution.berkeley.edu/evolibrary/about.php. Here we will limit our review to assessments and results relating to audience breadth, teaching, learning, and changes to the site motivated by evaluations.

General methods

Because of the number of components involved in the UE formative and summative assessments, a full description of the methods for each component cannot be included in this overview. However, methodological details are available in our supporting online materials, noted above. Those resources include instruments, administrative protocols, sampling procedures, and methods for the evaluation components cited herein, as well as additional results. Here, we will provide a brief summary of the most important aspects of the evaluation methods and throughout will reference individual components with dated identifiers (e.g., Spring '04 survey) corresponding to our supporting online materials.

REA researchers analyzed the log files of the UE teacher's site component for the 16-month period from January 29, 2004 to June 9, 2005 (Spring '05 log file analysis). The log files reflect usage by capturing hits, page views, and visits, and were analyzed with Sane Solutions' NetTracker 7.5 Professional software. Visits from UCMP and REA staff, as well as activity from spiders/robots, were filtered out of the data prior to analysis.

Most other evaluation activities were performed by REA with the participation of educators drawn from a national database. The database included K-16 educators who had previously attended UCMP-sponsored workshops on evolution and educators who were referred by teacher associations, science and science education organizations, school districts, and fellow colleagues, as well as educators who signed up after browsing UE.

The sampling strategies for these evaluation activities were random and purposive, depending on the location of the activity and the questions being addressed. For most of the activities, to the greatest extent possible, evaluators aimed for a broad representation of geographic areas, grade levels taught, and teacher expertise in evolutionary biology.

In addition, more elaborate evaluations were performed by REA on two resources (*The Arthropod Story* and *Survival of the Sneakiest*). For these evaluations (Spring '05 Arthropod evaluation and Fall '05 Survival evaluation), local Bay Area teachers were recruited to test the modules with their classes and to administer surveys and pre- and post-tests designed by UCMP to test whether students had learned targeted concepts. Pre- and post-tests incorporated true/false, multiple choice, and free response items. All free response items were scored blind by REA using standard scoring rubrics.

Audience depth and breadth

During the 16 months for which the site's log files were analyzed (Spring '05 log file analysis), the number of unique visitors to the site ranged from 8,162 to 37,760 per month. At least 20% to 24% of visitors returned after a previous visit. Although 60% of all visits to the site were less than 1 minute in duration, 12% lasted 15 minutes or longer – with some longer than 2 hours. Furthermore, recent data gathered from the UE server suggest that site usage has hugely increased within the last year: UE received approximately 1.5 million successful page requests during November 2005, compared to around 320,000 during November 2004. Together, these results indicate that UE is significantly engaging a large number of visitors.

Figure 4 illustrates trends in site visitation during the log file analysis. The dips in visitors in December 2004 and in Summer 2004 support the inference that a large proportion of the visitors are educators who use the site primarily during the school year. Data on user domains also suggest that U.S. educators were the primary users of the site. The U.S. domain that delivered the greatest proportion of visitors was U.S. educational (.edu), representing 70% of site visits from known U.S. domains.

FIGURE 4. Number of unique, new, and repeat visitors per month to the UE site during the log file analysis

Other inferences about the site's teacher population can be drawn from the log file analysis. The site received its heaviest use during the spring semester months (see Figure 4), perhaps suggesting that more educators teach evolution at that time of year. Furthermore, based on the grade levels of lessons viewed on the site (approximately 50% of lesson searches specifying a grade level selected high school level lessons), it appears that high school science teachers use the lesson database *most frequently*, followed by middle school and then elementary science teachers.

Use and impact on teaching

Teachers seem to regard the site as a useful support and guide for their evolution teaching. Several different evaluation activities asked teachers about the extent to which the website was, or could be, useful in their teaching. The Spring '04 survey asked teachers to rate the usefulness of the website for teaching evolution. On average, the respondents rated the site as "very useful" (a score of 3.86 out of four possible points on a Likert scale, N = 22). Other surveys produced similar results. A separate series of interviews (Spring '05 interview, N = 6) found that teachers using the site in their teaching tend to visit it repeatedly, making approximately ten to 16 visits to the site over the course of two to six weeks. Such results strongly suggest that teachers find the site to be a useful tool. This is supported by comments teachers made in the Spring '04 survey:

> I found this website as I was beginning our evolution unit for the year. I found many (more than I could use) activities, and I have my students do a webquest where they used your site for most of their research.
>
> I found the site useful in all areas. My evaluation took a long time because as I was evaluating I would find information or lessons and then I started printing out items to use in my class right away.

Teachers seem to find many different aspects of the site useful for improving their teaching. In the Spring '04 survey, teachers reported that the lessons greatly expanded their repertoire of strategies for teaching difficult evolution concepts and facilitated connections between major science concepts. One teacher reviewer in the Fall '03 section review honed in on the *Misconceptions* section noting that it "organized the various misconceptions about, and objections to, evolution in a very concise, manageable, understandable way. When these misconceptions are clearly stated and organized, it becomes much easier to correct or refute them." In a Spring '05 interview, another teacher focused on the *Quick Quizzes*, noting that they helped her to "formulate answers to questions my kids will have."

Teachers also reported that the site changed their attitude towards teaching evolution. The Spring '04 survey found that on average teachers "agreed" to "strongly agreed" both that UE increased their interest in teaching evolution and that UE increased their comfort in teaching evolution. Further,

interview data (Spring '05 interview) suggested that the website increases teachers' level of comfort or preparedness for teaching evolution, regardless of level of previous experience in teaching evolution.

The site also seems to have a significant impact on the ways teachers teach. Teachers in the Spring '04 survey indicated that on average, the website had an influence on their evolution teaching practices. Only two of the 22 respondents reported no influence. Furthermore, 16 of the 22 respondents reported that the website influenced their teaching of *other* areas of science. The nature of these changes seems to be towards more interactive, inquiry-based teaching, based on several interviews and surveys in which those features of the lessons were praised by teachers. Teachers in the Spring '04 survey also commented about the site:

> It has reminded me to emphasize the true nature of science in terms of being a constantly changing body of knowledge that is constantly reviewed and revised.
>
> This now allows me to incorporate more technology [into my curriculum].

Such positive interpretations are also supported by interview results, in which three out of four teachers indicated that the site had influenced their teaching (Spring '05 interview). As one of those teachers commented:

> Instead of just lecturing or having [students] read the information, or else doing an activity where they pretty much know the answer, these activities are geared toward having them find out the answer.... I teach evolution using much more exploration/inquiry now.

Teacher learning

In general, teachers who reviewed sections of the site reported that the content either improved or refreshed their understanding of evolution concepts (Fall '03 section review). This is reflected in their comments:

> I am more confident about understanding subtle differences in thoughts about evolution: how vs. whether.... I better understand how the choice of words is extremely important.
>
> I have had difficulty in understanding cladograms.… I now think I understand basically how they work and why they are important to understand.

These conclusions are also supported by the Spring '04 survey in which, on average, teachers "agreed" to "strongly agreed" that because of UE, they better understood evolution and the relevance of evolution to society.

Pre/post assessments of teacher knowledge are the clearest indicator that teachers improve their understandings of evolution as a result of using the site. On average, respondents scored 68% correct on a pre-test on evolution and 79% correct on the post-test taken after viewing the site ($p < .01$, $N = 97$, Winter '04 assessment).

Student learning

Teachers interviewed reported that their students enjoyed activities from the lesson database (Spring '05 interview). Most felt that it piqued their students' interest in evolution, in part because it made evolution and the scientific process, "more real to them." The hands-on classroom activities were viewed as especially engaging for students, and students reportedly benefited from the immediate feedback of the web-based activities. Some of these teachers reported that UE helped them to teach evolutionary concepts to students who are otherwise reluctant to learn about evolution.

The UE comic, *Survival of the Sneakiest*, which teaches the concepts of sexual selection and fitness, was evaluated directly with middle and high school students (Fall '05 Survival evaluation). Overall, findings revealed that non-English-language-learning middle and high school students learned from and enjoyed the comic. In response to an open-ended survey question, three-fourths of students reported that they felt they learned something new from the comic, most often information on mating behaviour and fitness (N = 132). Further, the comic was effective at increasing students' conceptual understanding of evolutionary fitness, as revealed by students' performance on pre- and post-tests designed to assess that understanding. Students had a mean pre-test score of 4.41 out of 11 and a mean post-test score of 5.99 out of 11 ($p < .05$, N = 134).

Also, the UE interactive module, *The Arthropod Story*, which teaches a number of evolutionary concepts in the context of an investigation of the evolution of arthropods, was evaluated directly with middle and high school students (Spring '05 Arthropod evaluation). In response to an open-ended survey question, 89% of middle school students (N = 87) and 78% of high school students (N = 79) reported that they felt they learned something new or exciting from the module, most often information on arthropods (their traits, evolution, and/or diversity). Further, pre- and post-test scores reveal that the module was effective at increasing students' conceptual understanding by more than 150% (see Table 2).

TABLE 2. Change in mean test scores after using *The Arthropod Story*. The maximum number of points possible on each test was eight points. Each score gain is statistically significant ($p < .05$)

	MEAN TEST SCORES		
Test:	High schoolers (N = 78)	Middle schoolers (N = 89)	Overall (N = 167)
Pre-test	1.92	1.92	1.92
Post-test	4.97	5.60	5.31
Average score gain	3.06*	3.68*	3.39*

Response to evaluation feedback and formative evaluations

REA evaluators shared findings from the evaluation activities on a periodic basis with UE developers, who used this feedback to guide the development and refinement of the site. Many of the changes motivated by the formative evaluations involved usability issues, such as navigation, formatting, and search options; however, other changes were more content-oriented. For example, a lesson that teachers in the Fall '04 survey deemed not very useful was dropped from the site. In another case, discussion questions and suggestions for classroom use were added to a resource at teachers' recommendations (Fall '05 new features formative evaluation).

One of the most important results to come out of formative evaluations was that many teachers either did or planned to send their students directly to the site for some part of their instruction. For example in the Spring '04 survey, more than one-third of the respondents referred their students directly to the site for independent work. Similarly, webmaster comments suggested that many of members of the general public accessed the site for personal use. These sorts of results and feedback motivated the development of a second site component targeting students and the general public, as outlined in the *Project Description*. The UE teacher's site component remains fully functional and fully integrated within the updated site.

CONCLUSION

Based on available evaluations, the Understanding Evolution website appears to have effectively met its goals: improving both teachers' understandings of evolution and their confidence to teach evolution, as well as providing resources for students and the general public to directly improve their own understandings of evolution. However, it is important to note that, though extensive, site evaluations only addressed the short term impact of materials. Ideally, evaluations would track teacher use over time and assess the impact of the site on teacher and student knowledge long after exposure to site materials. Such longitudinal studies are key in addressing the lasting impact of the site but were, unfortunately, beyond the scope of the project's initial assessment plan and funding. As UE continues to grow and the site is incorporated into and adapted for other educational projects, new opportunities for more extended assessment may arise. Nevertheless, even in the absence of such longitudinal evaluations, the results of initial assessments strongly suggest that the site has the potential for such long term positive outcomes and is, at least, effective at improving understanding of evolution and confidence to teach evolution in the short term.

The success of the Understanding Evolution website lies in its content and its construction, as confirmed by our formal evaluation, comments from users, and the growing and diverse international audience that is benefit-

ing from the site. Content was developed around well-documented needs – the need for robust but understandable science content, up-to-date and relevant information capable of targeting different learning and interest levels, and reliable and appropriate teaching resources and strategies. We purposefully elected to maintain a practical and scientific perspective for the site in order to avoid diluting accurate science and sound pedagogy with the "controversy" over evolution, which dominates public discussions of this topic. As a result, the site filled an anticipated niche and served an eager audience interested in improving their own knowledge and sharing that knowledge with others.

The collaborative development approach – scientists working with teachers and web developers – provided the expertise necessary to build a product that recognizes its audience's needs and preferences, while maintaining a high degree of scientific accuracy. For teachers, the site provides a complete suite of resources for improving content knowledge and classroom teaching on the topic of evolution. For students and the general public, the site provides an environment in which topics can be explored at different depths and in which highly complex concepts are reinforced through an integration of graphics, links, and interactivity. The site is comprehensive, engaging, flexible, and dynamic to encourage extended and return visits. It continues to grow and be refined as users' needs are identified and as the science behind the site advances.

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