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Preparing teachers to prepare students for post-secondary science: Thoughts from of a workshop about evolution in the classroom

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Abstract

This paper summarizes the content and results of a workshop about the teaching of evolution presented to public middle school and high school science teachers by individuals involved both in university education and the professional development of teachers. The goals of the workshop were to: (1) provide teachers with knowledge and resources to more effectively teach evolutionary theory, (2) increase teacher awareness of legal and cognitive issues associated with the teaching and learning of evolution, (3) address teacher misconceptions about evolutionary theory, (4) assess teachers' acceptance of evolutionary theory, and (5) make inferences about the preparedness of Arizona's public school students for a rigorous university life science curriculum that includes evolutionary biology. Participating teachers created concept maps about evolutionary theory, completed the Measure of Acceptance of the Theory of Evolution (MATE) survey at the beginning and end of the workshop, and responded to a survey the week following the workshop. The results of these measures indicate that some Arizona science teachers have misconceptions about evolutionary theory that may be passed on to their students, and these misconceptions, if not corrected, must be addressed in introductory-level science courses at the university level. Based on feedback from the follow-up survey, different teachers with varying acceptance of evolution are all keen to learn from university educators and attend professional development workshops. Such workshops – and engagement between secondary and tertiary educators - can clearly have an effect on the conceptions of both teachers and students, and thus on the acceptance of evolution. We therefore strongly encourage the involvement of university educators in science education outreach that addresses evolutionary theory.

Keywords: Workshop, evolution, teachers, science education, outreach

As America's need for professionals in science, technology, engineering, math (STEM) and health and medical fields increases, so does the need for rigorous pre-collegiate science curricula and high quality teaching of those curricula. To better prepare future high school graduates for college-level science coursework, the strengths and weaknesses of pre-collegiate education systems must be assessed and directly addressed. In addition, college and university educators must be made aware of how prepared their incoming students are and how and why they are so prepared. What is achievable in the classroom

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is highly dependent on the foundation laid during a student's secondary education. Thus, engagement between secondary and tertiary level educators benefits both groups in substantial ways.

One particular area of science education which suffers from weaknesses is the teaching of evolutionary biology in public school science classrooms. Due to social, political, legal, ethical, and/or scholarly issues associated with the teaching of evolution (enumerated and discussed in great detail elsewhere in the science education literature), public high school biology teachers might not teach evolutionary theory, even if it appears in their state education standards (Moore, 2002). Hessler (2000) concluded that 40% of biology teachers in Minnesota, a state with above average coverage of evolution in its state standards, spend little or no time teaching evolution (Lerner, 2000; Moore, 2002). Rutledge and Mitchell (2002) reported that 33% of 552 Indiana public high school biology teachers surveyed in 1995 spent fewer than three days addressing evolution in their classes, though Indiana has excellent coverage of evolution in its standards (Lerner, 2000). A survey of 1369 Minnesota university students who attended public high school found that 24% of those students were not taught evolution in their high school biology courses (Moore, 2007). Twenty-two percent of those students also reported that their teachers taught both evolution and creationism (Ibid.).

Moore (2004) suggested that teachers' refusals to teach evolution are due to pressure (from school boards and/or parents), unfamiliarity with laws about teaching religion in schools, lack of time, and/or lack of training (see also "Science Teachers Report Feeling Pressured to Teach Evolution," 2005 and Moore & Kramer, 2005). Indiana public high school biology teachers demonstrated "only a moderate level of understanding of evolutionary theory," providing correct responses to only 71% of questions testing their knowledge of the subject (Rutledge & Warden, 2000). Rutledge and Warden (2000) reported that many teachers had difficulty with questions related to the following concepts: environmental change, reproductive success, the process of evolution, the role of genetic variability in natural selection, the approximate date of the first life on earth, and radiometric dating principles. Rutledge and Mitchell (2002) reported on the 235 Indiana teachers who, in addition to completing the above-mentioned survey, also constructed a concept map about evolution that was used by the researchers to assess the teachers' conceptions of evolutionary theory. One misconception identified in the concept maps was the characterization of evolution as "only a theory" or "only a hypothesis" (Rutledge & Mitchell, 2002, p. 24).

Teachers' own acceptance of biological evolution also influences how they approach the subject in their classrooms. Rutledge and Mitchell's (2002:22) survey showed "a significant association between teacher acceptance of evolutionary theory and the amount of time devoted to evolution in the school year." Of the teachers surveyed, 33% were undecided about or not accepting of evolutionary theory and 43% reported that they either avoided or only "briefly mentioned" evolution in their classes (Rutledge & Mitchell, 2002, p. 22). Weld and McNew (1999) found that approximately one-third of teachers in Pennsylvania did not accept evolution as being central to biology and more

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than one-third of teachers in South Dakota supported the teaching of creationism in science classrooms.

These results are significant because research has shown that students' knowledge structure tends to reflect that of their teachers (Bates, 1976 and Diekhoff, 1983 cited in Rutledge & Mitchell, 2002; Moore & Cotner, 2009). Recent research by Moore and Cotner (2009) also shows that university students' attitudes toward evolutionary theory and creationism strongly reflect - though are not solely based upon - how their high school biology teachers addressed the topic of evolutionary biology. One thousand eight students at a state university in Minnesota were surveyed using the Measure of Acceptance of the Theory of Evolution (MATE) instrument created by Rutledge and Warden (1999) and reliability-tested by Rutledge and Sadler (2007). Those students whose public high school biology teachers taught evolution (and not creationism) were more accepting of evolutionary theory than those students who were taught creationism (with or without evolution; Moore & Cotner, 2009, p. 430). This implies that if public high school biology teachers are unaware that public schools are required to be religiously neutral according to the First Amendment of the Constitution (therefore making the teaching of creationism as the explanation for life's origins in biology class illegal) and/or have misconceptions about evolutionary theory, students may enter college with preconceptions about the epistemology of evolutionary biology and/or may lack knowledge of evolutionary theory all together.

College and university instructors would benefit from an awareness of the misconceptions of high school biology teachers for two major reasons. Firstly, such knowledge would allow us to teach more effectively; if we know the misconceptions that our incoming students inherit from their teachers, we can design coursework to correct these ideas sooner rather than later in the student's college career. Secondly, it encourages us to be proactive in aiding the professional development of teachers to prevent misconceptions from being taught in the first place. This can be made particularly relevant for those instructors who are employed by state universities or colleges where a majority of the student body hails from the state in which the institution is located. One such institution is Arizona State University (ASU).

On May 9, 2009, a teachers' workshop titled "Translating Evolutionary Science into the Public Classroom" was presented to Arizona public middle school and high school science teachers on the Tempe campus of ASU as part of a year-long series of events in celebration of Charles Darwin's 200th birthday (darwin.asu.edu). ASU is a public university that, in Fall 2007, had over 50,000 full-time equivalent (FTE) undergraduate students enrolled in the University's various colleges, including over 22,000 in the College of Liberal Arts & Sciences and nearly 3,000 in Education or Teacher Education (ASU Fact Book, 2007-2008). The student body included 40,000 students who had a permanent address in Arizona at the time of enrollment and approximately 90% of those Arizona students had permanent addresses in Maricopa County, where ASU is located (ASU Fact Book, 2007-2008).

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Despite the large number of Arizona students attending ASU, only about 50% of Arizona's 2006 high school graduates qualified to enter one of its three state universities ("Arizona High School Eligibility Study," 2006). In 2005, 51% of Arizona's eighth grade public school students were performing below the basic level of achievement in science ("The Nation's Report Card," 2008). And in 2008, Arizona high school students (many of whom were in eighth grade in 2005), took the first science exam administered as part of the Arizona Instrument to Measure the Standards (AIMS); more than 62% of those students who took the science portion failed it (Madrid, 2008). Though the science AIMS test is *not* a requirement for graduation from Arizona's public high schools, unlike the reading, writing and math portions of the AIMS, the Arizona State Board of Education will require three credits of science "in preparation for proficiency at the high school level on the AIMS test" for the class of 2013 (Arizona Administrative Code, 2009). This means that Arizona science teachers are more obligated than before to teach evolutionary theory because questions pertaining to evolution appear on the AIMS science test. As a result, many teachers will need professional development opportunities, such as university-lead workshops, on evolution.

The issues surrounding the teaching and learning of evolution in Arizona's public schools concern not only potential high school graduates, but all students who attend ASU. ASU requires that all students in a bachelor's degree program fulfill 35 semester hours of approved general studies courses, including eight semester hours of "Natural Sciences." Courses that may fulfill these requirements include (but are not limited to), *General Biology I* (BIO187), which deals extensively with evolutionary theory, and *Bones, Stones and Human Evolution* (ASM104), an introductory physical anthropology course based almost exclusively on the principles of evolutionary theory[2]. Many non-science majors enroll in these courses to partially fulfill their general studies hours; of 1080 undergraduate degree students with a declared major who signed up for ASM104 between Fall, 2003, and Spring, 2007, only 121 were Anthropology majors. Therefore, adequate training in high school biology can potentially contribute to the success of students of all majors at ASU[3].

The foundations for the "Translating Evolutionary Science into the Public Classroom" workshop were the relatively new standards-based emphasis on teaching and learning science in Arizona's public schools, the need to better prepare Arizona's middle and secondary school students for challenging science coursework at the university-level, and the myriad concerns, social, political, psychological, legal, and scholastic, that teachers have about the teaching of evolution in their schools. Therefore, the goals of the workshop were to: (1) provide teachers with knowledge and resources to more effectively teach evolutionary theory, (2) increase teacher awareness of legal and cognitive issues

[2] Students who receive a score of 4 or 5 on the Advanced Placement (AP) Biology exam in high school receive 8 general studies hours, equivalent to BIO187 and General Biology II (BIO188). Although approximately 75% of the AP Biology curriculum is based on evolutionary theory (College Board AP, 2009), some ASU students report that they did not learn about evolution in their AP Biology courses (CMS, unpublished data).

[3] In the 2007-2008 academic year, 16.85% of students who completed BIO187 received a grade of D or E (the equivalent of an F at other universities; azcentral.com Data Center, 2009). From Fall, 2003, to Spring, 2007, 7.5% of students enrolled in ASM104 withdrew and 13.6% received a D or E.

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associated with the teaching and learning of evolution, (3) address teacher misconceptions about evolutionary theory, (4) assess teachers' acceptance of evolutionary theory, and (5) make inferences about the preparedness of Arizona's public school students for a rigorous university life science curriculum that includes evolutionary biology. In what follows, we summarize the components of the workshop, but focus on the results of the measures of teacher acceptance and conceptions of evolutionary theory. In so doing, we hope to demonstrate how and why educators can and should be involved in improving student preparation for college and university science coursework to ultimately maximize the achievements of tertiary educators in their own classrooms.

Workshop Summary and Outcomes

Applications for participation in the evolution workshop were solicited from public school science teachers in Arizona and thirteen teachers were accepted. At the time of the workshop, two teachers were employed at middle schools and eleven teachers were employed at high schools, all within 50 miles of ASU. The experience of the teachers ranged from 1-2 years to more than 21 years of teaching science in public schools. Science classes taught by the participants included, but were not limited to, 7th grade science, 8th grade science, Biology, Honors Biology, AP Biology, International Baccalaureate (IB) Biology, Anatomy and Physiology, Earth Science, and Environmental Science. Teachers were compensated with a stipend upon completing the workshop. Table 1 summarizes the results of a follow-up survey question that asked the teachers to indicate why they attended the workshop (teachers were given 6 provided responses and an option to write-in a response).

The teachers were given four pre-workshop reading assignments culled from material from the National Center for Science Education, Nature Magazine, and the National Academies Press. The workshop was divided into seven mandatory sessions with an optional eighth session. The sessions, with a short description, are listed in Table 2. The total contact hours between the teachers and workshop faculty were seven and one half.

Teacher acceptance of evolution

The Measure of Acceptance of the Theory of Evolution (MATE) survey created by Rutledge and Warden (1999) was given to the teachers at the beginning of the workshop and again after session 7 (see Rutledge & Sadler, 2007, for a discussion of the reliability of and concepts addressed by the MATE). Teachers were asked not to write their names on the MATE, however all participants optionally provided their gender and/or age. The goals of administering the MATE twice were to assess the consistency of the teachers' responses and note any potential influences of the workshop on their acceptance of evolution (these cannot be clearly distinguished). The MATE includes twenty statements to which the teachers were required to respond "strongly disagree," "disagree," "undecided," "agree" or "strongly agree." Individual answers were scored using Likert scaling (1 = low acceptance of evolutionary theory and 5 = high acceptance of

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Table 1. Responses of teachers about why they attended the workshop (*n = 8*).

Statement: "I attended the workshop…"	**Strongly Disagree**	**Disagree**	**Un-decided**	**Agree**	**Strongly Agree**
to increase my working knowledge of the principles of evolutionary theory.				1	7
to learn more about the laws associated with the teaching of evolutionary theory.	1			2	5
to learn more about how to properly address the evolution/creationism issue in my classroom.	1			2	5
to learn about other teachers' experiences with teaching evolutionary theory in their classrooms.			1	5	2
to learn about resources for teaching evolutionary theory effectively (e.g., print and web resources).					8
because of the stipend.		4		4	

evolutionary theory) and, based on their total score, teachers' responses were assigned to an acceptance category created by Rutledge (1996; see Table 3).

The mean score for the pre-workshop MATE was 89.9 and the mean for the post-workshop MATE was 93.3 (both "very high acceptance"). Six respondents' category of acceptance of evolution changed from "high" to "very high," but three individuals had a lower score on the post-workshop MATE than the pre-workshop MATE (by 9, 10, and 3 points), causing two of them to drop from the "very high acceptance" category into the "high acceptance" category. The teacher whose score dropped by 9 points changed his/her view about items related to the evolution of humans, a topic that was not specifically addressed in sessions 1-7. The participant whose score dropped by 10 points primarily changed his/her responses to items concerning the support - both evidence-based and in the scientific community - for evolutionary theory. it is unclear what aspect(s) of the workshop, if any, lead these teachers to change their views. There was no

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Table 2. Workshop sessions

Session	Description
1. Concept Mapping	Teachers were introduced to concept mapping as a tool for assessing knowledge structure (Novak and Cañas, 2006) and were given a focus question for constructing their own concept maps about evolution which were used by the workshop leaders to assess their conceptions of evolutionary theory.
2. Presentation: "Teaching Evolution One Icon at a Time"[4]	Teachers were introduced to the strategies (e.g., "intelligent design", "teach the controversy" or "teach the strengths and weaknesses of evolution") that are being used at the state and local level to weaken the teaching of evolution and ways of dealing with those strategies were discussed.
3. Presentation: "Why is evolution so hard to accept?"	The session addressed innate and developmental biases that encourage people to look for centralized, intentional agents as causal forces, making evolution counterintuitive.
4. Presentation: "Evolution, Creationism and the courts"	Teachers were provided with a summary of recent court cases and legal issues surrounding the teaching of evolution and creationism in America's schools.
5. Web exploration	Teachers were introduced to online biology resources and given the opportunity to explore the World Wide Web to search for resources about evolution (and issues surrounding evolution and creationism).
6. Misconceptions about evolutionary theory	This session addressed misconceptions identified in the teachers' concept maps (constructed in session 1).
7. Presentation: Evolution, standardized tests, and preparing for college	Discussion of evolution in standardized exams, such as the AIMS science test and AP Biology exam, requirements for graduation from AZ high schools and general studies requirements for ASU students.
8. Optional tour of ASU's Institute of Human Origins (IHO)	Teachers were given an overview of the subject matter that can be presented by researchers to students on a field trip to the IHO.

[4] Slides from this session are available online at http://www.slideshare.net/jmlynch/teaching-evolution-one-icon-at-a-time.

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Table 3. Results of MATE survey (n=12[5])

Catergory of Acceptance (MATE score)	pre-workshop MATE	post-workshop MATE
Very high acceptance (89-100)	6	10
High acceptance (77-88)	6	2
Moderate acceptance (65-76)	0	0
Low acceptance (53-64)	0	0
Very low acceptance (20-52)	0	0

single item for which every participant provided the same response on the post-workshop MATE as he/she did on the pre-workshop MATE.

Though confounding factors and small sample sizes prevent us from identifying a statistical correlation between attendance at the workshop and level of acceptance of evolution, comparisons of pre- and post-workshop MATE responses indicate that the majority of teachers were more confident about the scientific basis for evolutionary theory after completing sessions 1 through 7. The item for which the mean score increased the most (1 point) from pre- to post-workshop was the statement, "Current evolutionary theory is the result of sound scientific research and methodology." In the follow-up survey, participants were asked: "How has your attendance at this workshop affected your confidence about teaching the material (i.e., vocabulary, concepts, etc.) associated with the topic of evolutionary theory?" Seven out of eight respondents reported that they felt "more confident" or "much more confident" (one respondent reported no change). In reply to the question, "Given any social, legal, or ethical concerns you may have, how has your attendance at this workshop affected how you feel about teaching evolutionary theory in your classroom?," six of eight participants said they felt "more comfortable" or "much more comfortable" (two respondents reported no change). This is theoretically significant because teachers' acceptance of evolution correlates with the amount of time spent teaching about evolution in their classrooms (Rutledge and Mitchell, 2002). Therefore, if teachers' acceptance of evolution as a scientifically valid theory can be increased, the likelihood that they will spend more time teaching about evolution is increased. And, if one assumes that the quality of teaching about evolution is, in part, related to teacher confidence and comfort, then, overall, this type of professional development for teachers would lead to better preparation of middle or secondary school students for a college or university life science curriculum.

[5] One teacher did not respond to the pre- or post-survey using the responses required, so his/her surveys were not included.

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Teacher conceptions of evolution

The first session of the workshop comprised a discussion of concept maps as "graphical tools for organizing and representing knowledge," an introduction to web-based concept mapping software (CmapTools), and an exercise requiring the teachers to construct their own concept maps about evolution (Cañas et al., 2004; Novak and Cañas, 2006:1). Some teachers indicated that they had used concept maps previously in their classrooms.

At the start of this session, one of the workshop leaders discussed some mechanisms of evolutionary change with the teachers and wrote these on a white board. The teachers were then given a focus question on which to base their concept maps: "What are the components and implications of evolutionary theory?" Teachers were permitted to use the discussed mechanisms as part of their parking lot[6] for constructing their concept map. The leader encouraged the participants to put 15-20 words or short phrases in their parking lot before constructing their concept maps. Participants had approximately 20 minutes to complete this exercise.

The teachers' concept maps were collected and analyzed by workshop leaders to identify misconceptions about evolutionary theory[7]. The most common misconceptions noted in the concept maps fell into three categories: misconceptions about Charles Darwin's role or discoveries, about mechanisms of evolutionary change, and about the meaning of commonly used terms or phrases in evolutionary biology. Instead of presenting the teachers with a list of their misconceptions, scientifically accurate statements were provided that addressed the concepts teachers had trouble with, ensuring that their notes from this session would include information that was scientifically correct (see Table 4).

The workshop session addressing teacher misconceptions was well received by the participants. Seven of eight respondents to the follow-up survey reported that they were "satisfied" or "very satisfied" with the session. Open-ended feedback about this session included the following: "*This was the best part of the entire day…I believe that there are numerous misconceptions about the whole process of evolution and the history behind it. I know that I have some. As an educator it is so difficult to find time to read all that is out there and it is wonderful to have an expert in the field clarify some of those. I would really enjoy attending workshops that deal* [just] *with misconceptions and the content area of the theory."*

This feedback indicates to us that there are teachers eager to learn from professionals in the sciences about the evidence for evolution and history of evolutionary theory. This passing of knowledge from expert to teacher would affect classroom instruction, and presumably, classroom learning. Approximately 86% of participants indicated that the content of session six would "likely" or "very likely" affect their approach to teaching

[6] A "parking lot" is a list of terms or short phrases associated with the topic in question and can be used later to construct the concept map (Novak and Cañas, 2006).

[7] One teacher constructed a map closely resembling a string map (see Novak and Cañas, 2006:11) and one teacher did not use linking words at his/her cross-links, which made them more challenging to analyze than the others.

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Table 4. Scientifically accurate conceptions intended to address common misconceptions of teachers

Topic	Concept
Charles Darwin's Role and Discoveries	Darwin did not invent the idea of biological evolution.
	The Galapagos Islands and their finches played a relatively minor role in the development of Darwin's idea.
	Darwin was not aware of Gregor Mendel's work.
	Darwin accepted other mechanisms of evolutionary change besides natural selection.
Mechanisms of Evolutionary Change	Today we accept natural selection, mutation, genetic drift and gene flow as separate mechanisms.
	Natural selection has no forethought.
	Natural selection *is* differential reproductive success, not the *cause* of it.
	Natural selection (or evolution generally) is not driven by mutation.
	Fitness refers to reproductive success.
	Fitness is defined relative to an environment – environmental change leads to different selection pressures.
	Artificial selection is usually done with some goal in mind – natural selection is not thought of as goal-oriented.
Commonly used phrases or terms	"Missing link" has been a misleading term that has implied that there is a direct evolutionary sequence among living species.
	"Survival of the fittest" is misleading shorthand for natural selection. There are many reasons besides actually dying that lower reproductive success.

evolution. It is therefore crucial for experts in the fields of life sciences, geology, the history of science, psychology of education, and others, to work with elementary and secondary school educators to clarify the epistemology of evolutionary theory and improve public school science pedagogy. The pragmatic benefit of this for tertiary-level instructors would clearly be less time and effort spent battling the misconceptions their students have carried over from their earlier school days.

Conclusions

As part of the follow-up survey, 100% of the participating teachers indicated that they would recommend this evolution workshop to other educators, though 80% said they would prefer a multi-day workshop with more content to a single-day workshop with the

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content described above. The greatest proportion of criticism related the teachers' dissatisfaction with the amount of time dedicated to particular sessions. Many of the teachers wanted to spend more time in session 3, which addressed innate and developmental biases that make evolution counterintuitive. Only a short segment of the entire workshop was spent addressing specific content and misconceptions about evolution, and based on the follow-up survey, all of the teachers attended the workshop to increase their working knowledge of the principles of evolutionary theory and learn about resources for teaching evolution effectively (see Table 1). If this workshop were offered again, more time would be dedicated to biases, misconceptions, content and resources for teaching.

Clearly, there is a demand for professional scientists who are willing to reach out to educators in their community and share with teachers their expertise, which can then be passed on to school age students. One respondent wrote on his/her follow-up survey: "I would like to help ASU scientist[s] to translate/communicate their science to their future students, currently my science students." The benefits incurred by the tertiary educators reach beyond the personal rewards of community outreach and into their classrooms; if college and university educators can contribute to the knowledge, confidence, and comfort of America's public school teachers when it comes to teaching evolution, fewer teaching challenges will be met at the post-secondary level.

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