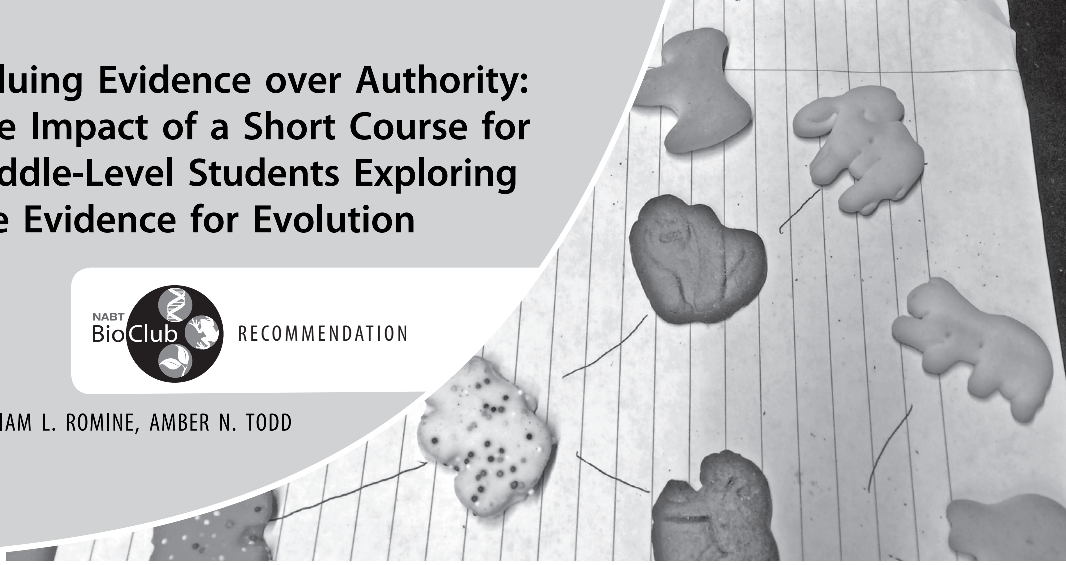
RESEARCH ON LEARNING

Valuing Evidence over Authority: The Impact of a Short Course for Middle-Level Students Exploring the Evidence for Evolution



NABT BioClub RECOMMENDATION

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Abstract

Increasing both knowledge and acceptance of evolution are important outcomes of efforts to educate our students about the theory of evolution. Data were collected in the context of an 11-day short course focused on examining the evidence for evolution at a suburban STEM school in the Midwestern United States to answer the following research questions: (1) What effect did this course have on knowledge and acceptance of evolution? (2) How did cognitive and affective factors support growth in understanding of evolution in this evidence-centered educational intervention? This short course, comprising 21 students, focused on exploration-based activities allowing students themselves to collect evidence for evolution. We found significant gains in knowledge of microevolution and macroevolution, and found that both prior knowledge and acceptance of evolution were important in facilitating students' conceptual growth.

Key Words: *evolution; microevolution; macroevolution; acceptance.*

○ Introduction

Whereas didactic teaching is built upon the framework of authority, inquiry-based teaching is built upon the framework of evidence, giving the student more control to direct his/her own learning by facilitating a continual interaction between the student and the content (Roth & Lee, 2004). For instruction about evolution, this involves presenting students with evidence of macroevolution, microevolution, and natural selection. Given that students have plenty of authority figures, the facilitator of inquiry banks on the idea that after his/her students themselves sense sufficient evidence for evolution, they will ultimately develop a conceptual framework that provides a balance between the need to consider their prior ideas and the need to understand scientific data that cannot be explained outside of the framework of evolution (Blackwell et al., 2003).

Facilitating learning about evolution in grades 6–12 has comprised a significant challenge over the past decade.

Here we focus on two questions: (1) What effect did an 11-day short course focused on examining the evidence for evolution have on knowledge and acceptance of evolution? (2) How did prior knowledge and acceptance of evolution support growth in understanding of evolution in this evidence-centered educational intervention?

Instructional Framework

Facilitating learning about evolution in grades 6–12 has comprised a significant challenge over the past decade. Many studies have attempted to address this problem from the perspective of teacher education, given that just over half of biology teachers teach evolution (Berkmann & Plutzer, 2011; Romine et al., 2014), and that many teachers have only moderate levels of knowledge and acceptance of evolution (Rutledge & Warden, 2000). The vast majority of educational interventions described at the student level are focused on college classrooms (e.g., Pimiento, 2015; Yamanoi & Iwasaki, 2015); however, since college student pre-test scores on knowledge of evolution tend to be deficient (Bishop & Anderson, 1990), instructional approaches targeting evolution knowledge and acceptance should start well before college.

A number of innovative methods for evidence- or data-focused evolution instruction have been described in the past two years. Some researchers have focused on tree thinking concepts (Davenport et al., 2015) or cladogram construction based on data (McCabe, 2014). Others have used finch beak data (Bierema & Rudge, 2014), bioinformatic data on antibiotic resistant strains of tuberculosis (Taylor et al., 2014), or digital evolution in the context of the Fukushima butterfly (Lark et al., 2014). Teachers have also had success using a Socratic method to respond to students' current conceptions about evolution (Stansfield, 2013). Virtual learning platforms have also increased in popularity; the Evolution and Nature of Science Institutes (ENSI)

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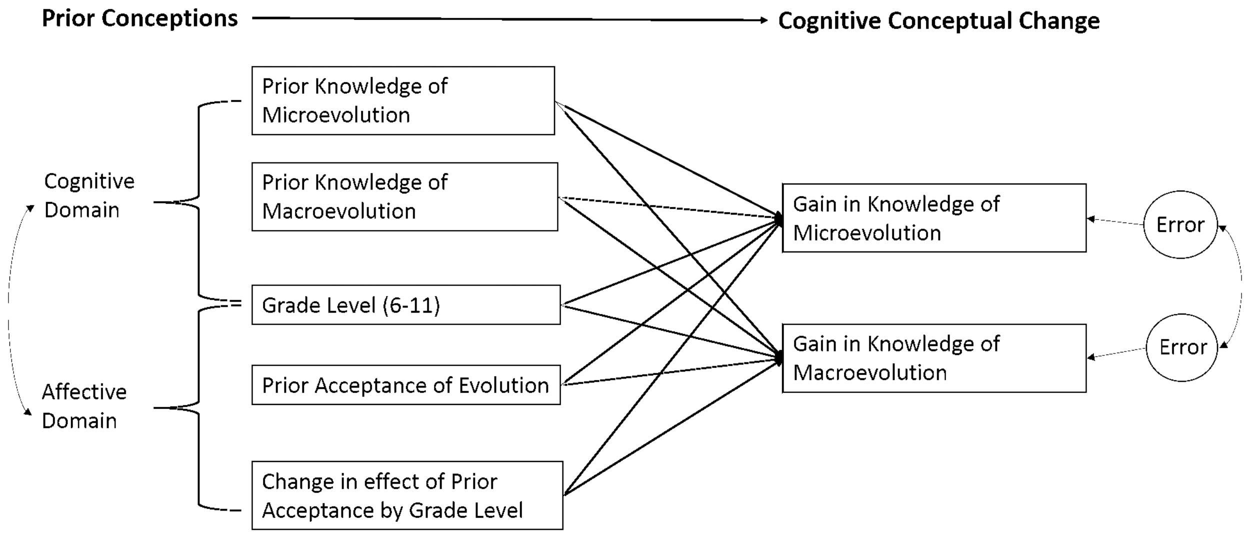

Figure 1. Both cognitive and affective factors influence the effectiveness of instruction in changing students' knowledge of evolution.

(Beard et al., 2014) and the Howard Hughes Medical Institute's (HHMI) BioInteractive provide a wide array of evidence- and data-focused learning activities.

In this study, we sought to develop inquiry-based instruction examining the plethora of evidence for evolution to facilitate, and assessments to measure, students' conceptions around evolution, including (1) knowledge of microevolution, (2) knowledge of macroevolution, and (3) acceptance of evolution. These three constructs represent an integration of both cognitive and affective factors (Figure 1). Given that many students' nonscientific conceptions about evolution stem from experiences based in their religion, the influence of the affective or acceptance domain within topics in evolution can be especially strong. Indeed, low acceptance of evolution leads to lack of perceived plausibility and fruitfulness of new ideas, therefore inhibiting students from changing their ideas (Posner et al., 1982). Along the same theory, students coming into instruction with lower amounts of prior knowledge are expected to find new ideas less intelligible, thereby increasing resistance to changing their ideas. This significant interaction between the cognitive and affective domain is supported by previous research (Nadelson & Southerland, 2010b), and some propose acceptance of evolution may even have a cognitive component (Deniz et al., 2008). We seek to test this framework holistically under the premise that the effectiveness of instructional efforts aiming to improve students' knowledge of evolution is influenced significantly by students' affective preconceptions in addition to the expected cognitive influence of prior knowledge (Figure 1). Given that Carter, Infanti, and Wiles (2015) suggest that evolution acceptance plays a critical role in students' success in introductory biology courses at the college level, K-12 teachers should work with students in fostering constructive attitudes about the theory of evolution.

Content of Instruction

We used our framework of increasing knowledge of evolution, being a combination of cognitive and affective factors, to create instruction for our evidence-centered short course. Table 1 details the instructional design of the short course, the activities and investigations conducted, the specific evidence for evolution the students encountered, and the connections to the Next Generation Science Standards (NGSS). As a part of the course, students were required to keep a field notebook or reflective journal where they made sketches of evidence discovered and reflected upon the various activities. During the first few days (Days 1–2), we explored the variety of cognitive and affective perspectives students and others may have regarding evolution (Table 1). We used small group and whole class discussion to brainstorm a list of things the students or others knew or thought about evolution (correct or incorrect), as well as questions they wanted to explore regarding topics in evolution. As university faculty, we then took advantage of opportunities at our university. We brought the students on campus to explore a research project, currently underway in the computer science department, that analyzes Twitter data to uncover what the general public feels and knows about evolution. The first few days laid the groundwork for students' understanding that people can and do hold a variety of different cognitive and affective perspectives regarding topics in evolution.

Our next instructional segment (Days 3–7) focused on macroevolution (Table 1). Knowing students may have difficulties accepting macroevolution (affective perspective), we sought to provide them with evidence of macroevolution from a variety of sources. We took two field trips to parks in the area where the students could observe geologic rock formations, hunt for fossils, and make sketches of fossils found. We watched videos and did activities about the age of the universe, deep time, and radioactive dating so students could grasp extended time frames and understand how radiometric dating for fossils and rocks works. We used HHMI BioInteractive resources on the Cretaceous-Tertiary (KT) boundary and the PBS series *Your Inner Fish* to expose students to scientists who study macroevolution and the evidence they have collected in support of macroevolution. The students also used HHMI BioInteractive to explore phylogenetic tree construction and completed an activity where they constructed a phylogenic tree

Table 1. Instructional Design and Activities Related to Topic and Evidence

Instructional Time	Topic	Description of Activity/ Investigation	Evidence	NGSS Connections
Pre-Assessment (Day 1)				
Day 1	Evolution as a whole	Explore what people know about evolution on the web. Class discussion about what they know or don't know about evolution.		HS-LS4-1
Day 2 (morning)	Evolution as a whole	Field trip to university to explore what the general public Tweets about evolution.		HS-LS4-1
Day 2 (afternoon)	Macroevolution	Observe and document similarities and differences in species observed outside in nature. Watch *Your Inner Fish* from PBS.	Structure/function evidence of similarities and differences between species.	MS-LS4-1, MS-LS4-2, MS-LS4-6, MS-ESS1-4, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Day 3	Macroevolution	Watch videos about the deep time and the age of the universe. Half-life activity of carbon dating.	Age of the Earth and universe.	MS-ESS1-4, HS-ESS1-6
Day 4	Macroevolution	PhET radioactive dating game. HHMI BioInteractive KT boundary videos and activities.	Age of the Earth, age of organisms on Earth.	MS-LS4-1, MS-LS4-2, MS-LS4-6, MS-ESS1-4, HS-LS4-4, HS-ESS1-6
Day 5	Macroevolution	Fossil hunt at local state park.	Age of the Earth, age of organisms on Earth, structure/function evidence of similarities and differences between species.	MS-LS4-1, MS-LS4-2, MS-LS4-6, MS-ESS1-4, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Day 6 (morning)	Macroevolution	HHMI BioInteractive phylogenetic tree activities.	Structure/function evidence of similarities and differences between species.	MS-LS3-1, MS-LS4-2, MS-LS4-6, HS-LS3-2, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Day 6 (afternoon)	Microevolution/ Natural Selection	Swab and plate bacteria samples from school on plates; add antibiotic discs to test resistance.	Organisms can evolve to develop resistance.	MS-LS1-5, MS-LS3-1, MS-LS4-4, MS-LS4-5, MS-LS4-6, HS-LS3-2, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Day 6 (afternoon)	Macroevolution	Create animal cracker phylogenetic trees. Watch *Your Inner Reptile* from PBS.	Structure/function evidence of similarities and differences between species.	MS-LS4-1, MS-LS4-2, MS-LS4-6, MS-ESS1-4, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Day 7	Macroevolution	Fossil hunt at local state park.	Age of the Earth, age of organisms on Earth, structure/ function evidence of similarities and	MS-LS4-1, MS-LS4-2, MS-LS4-6, MS-ESS1-4, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5

Table 1. Continued

Instructional Time	Topic	Description of Activity/ Investigation	Evidence	NGSS Connections
			differences between species.	
Day 7 (afternoon)	Microevolution/ Natural Selection	Look at bacterial plates, analyze and interpret findings.	Organisms can evolve to develop resistance.	MS-LS1-5, MS-LS3-1, MS-LS4-4, MS-LS4-5, MS-LS4-6, HS-LS3-2, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Day 8	Microevolution/ Natural Selection	HHMI BioInteractive *Beak of the Finch* video and activities. Clip Birds bird/beak activity. HHMI BioInteractive *Lizards in a Tree* video and activities. Look at bacterial plates, analyze and interpret findings. Watch *Frontline* "Hunting Nightmare Bacteria" video.	Organisms can evolve in a short amount of time given strong environmental pressures. Videos highlighted instances when scientists directly observed evolution happening.	MS-LS1-5, MS-LS3-1, MS-LS4-2, MS-LS4-4, MS-LS4-5, MS-LS4-6, HS-LS3-2, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Day 9	Microevolution/ Natural Selection	Activity with marshmallows, Skittles, and toothpicks to select "harmful" bacteria. Watch *Frontline* "The Trouble with Antibiotics" video.	Organisms can evolve to develop resistance.	MS-LS1-5, MS-LS3-1, MS-LS4-4, MS-LS4-5, MS-LS4-6, HS-LS3-2, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Day 10	Microevolution/ Natural Selection	Watch videos about artificial selection (royal families). HHMI BioInteractive "Birth and Death of Genes" video and activities. Analyze bacterial plates data.	Organisms can evolve over time, genes can be duplicated or destroyed to change organisms; evolution can happen through natural selection or artificial selection.	MS-LS1-5, MS-LS3-1, MS-LS4-4, MS-LS4-5, MS-LS4-6, HS-LS3-2, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Day 11	Microevolution/ Natural Selection	HHMI BioInteractive "Sickle Cell Anemia" video, lactose tolerance video. Protecting the herd/herd immunity activity. Frontline "Outbreak" ebola video. *Your Inner Monkey* from PBS.	Organisms can evolve over time due to environmental or cultural pressures; structure/function evidence and similarities and differences between species.	MS-LS1-5, MS-LS3-1, MS-LS4-2, MS-LS4-4, MS-LS4-5, MS-LS4-6, MS-ESS1-4, HS-LS3-2, HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5
Post-Assessment (Day 11)				

with animal crackers. In providing this extensive amount of evidence and experience with macroevolutionary ideas, it was our goal to influence both their knowledge of macroevolution (cognitive factors) and their acceptance of macroevolution (affective factors).

Our third instructional segment (Days 7–11) focused on microevolution (Table 1). As microevolution can be directly observable in a relatively short amount of time (compared to macroevolution), we focused on providing evidence that explains how scientists *can and have directly observed* microevolution. This was an important point for the students to understand—scientists have directly observed microevolution, so the "you can't observe it" argument against evolution is invalid. We used a number of HHMI BioInteractive resources (Darwin's finches, anole lizards, ice fish) as examples of observable microevolution. Students learned about antibiotic resistance and conducted their own experiments, testing different bacteria (swabbed from various things around the school) against different antibiotic discs. After students witnessed how some of their bacteria were resistant to certain antibiotics, we discussed "superbugs" and watched a *Frontline* episode discussing these "nightmare bacteria" and how they can cause severe illness. Our intention was for knowledge and acceptance of microevolution to increase and for students to be better able to explain how microevolution explains changes in species (e.g., Darwin's finches), including bacteria (e.g., bacterial resistance), after instruction.

Our last day of the short course (Day 11) centered on human evolution and current topics regarding evolution (Table 1). We used HHMI BioInteractive resources to discuss the link between sickle cell anemia and malaria, and how culture influenced the prevalence of lactose tolerance. We did an activity showing the importance of vaccinations in providing herd immunity, and watched current *Frontline* episodes that discussed the recent Ebola outbreak and antibiotic resistance. Overall, our short course was designed to provide a plethora of evidence of evolution to help facilitate students' acceptance of evolution and understanding that concepts in evolution are essential for making sense of natural processes related to health and biology.

Assessment of Instructional Effectiveness

Twenty-one students in grades 6–11 participated in this 11–day short course and took part in this study. Our school context was a suburban public school (grades 6–12) that has a project-based STEM focus. Aligning with this focus, students are required to choose a STEM-focused short course to participate in prior to the end of the school year but after regular courses are completed. Students receive a grade for their work in the short course, which appears on their school transcript. Faculty typically develop these short courses based on their interests (e.g., STEM in fashion, STEM in bike riding, etc.) or with assistance from regional experts (e.g., our course taught by university faculty). All participants were students who signed up to take the "Exploring Evolution" course, which was offered as one option for all grade 6–12 students. In describing our specific study context, we wish to note the limitations to our study, including sample size, lack of a comparison group, the nature of the school context being a STEM school, and that the students in our sample elected to be in a short course focusing on evolution. These limitations noted, we believe our context is uniquely able to help promote knowledge and acceptance of evolution in an intensive short course; teachers could use our instructional design to create their own intensive short course or summer program.

We used three validated instruments to assess each part of our conceptual framework (Figure 1): the Measure of Acceptance of the Theory of Evolution (MATE) (Rutledge & Warden, 1999) for evolution acceptance, the Concept Inventory of Natural Selection (CINS) (Anderson et al., 2002) for knowledge of microevolution, and a revision of the Measure of Understanding of Macroevolution (MUM) (Nadelson & Southerland, 2010a) for knowledge of macroevolution that addresses criticisms expressed in previous studies (Novick & Catley, 2012; Romine & Walter, 2014). Prior research with these instruments demonstrates validity and reliability sufficient for group or temporal comparisons (reliability > 0.7). Though these instruments are geared toward high school or college students, and none have been validated with students as young as 6th grade, students in our study did not express problems interpreting the questions. One of the strengths of our study was that, to assess knowledge of microevolution and macroevolution and acceptance of evolution, we used three validated instruments that are available to other researchers and teachers to use.

Reflecting upon Instruction

Our instructional context was unique, as we had a wide age range of students (grade 6–11) for an intensive 11–day short course focused only on evolution. Because our students chose to take the course (whether because of interest, other courses being full, a friend or sibling in the course, etc.), and the course was for a grade, students were fairly motivated to participate and engage themselves with the activities and different sources of evidence. The students indicated that their favorite activities were the fossil hunt field trips and any time they could go outside (i.e., Day 2 afternoon, Table 1). They also greatly enjoyed the PBS series *Your Inner Fish*. The students enjoyed the fossil hunts and made several interesting findings. They were asked to sketch their fossil findings in their field notebooks and were able to collect several fossils to bring back to the school and to their own homes. The fossils they found were predominantly coral, crinoids, trilobites, bryozoans, brachiopods, and cephalopods, consistent with the geology of the region; students displayed their fossil findings at an "exhibition night" where parents and the community were invited to the school to see the projects from the various short courses. The students excitedly showed off their findings and drawings to other students and teachers in the school.

Students also especially enjoyed culturing the bacteria they swabbed from various surfaces around the school and testing antibiotic resistance. Safety was a concern while doing this experiment, and adequate precautions were taken with the students. Students were given agar plates on which they streaked the bacteria swabbed from various items around the school. Once the plates were streaked, we (instructors) added the antibiotic discs, and the plates were not re-opened by the students. The plates sat in an incubator, and prior to distributing the plates to the students, we sealed them with parafilm to prevent the students from opening them. We (instructors) also handled disposal of the plates, and the students wore gloves and safety glasses at all times. Given all of these precautions and safety considerations, we were not hesitant to perform this experiment with grade 6–11 students. The students enjoyed seeing that certain naturally occurring bacteria harbored resistance to some antibiotics, and this connected well with the videos about "superbugs" and discussion about antibiotic resistance and the overuse of antibiotics.

Although our goal was to provide students with a plethora of evidence for evolution in hopes that the evidence would enhance their acceptance and knowledge of evolution, we were cognizant of overwhelming the students with content since the short course was an all-day experience. After activities, we asked students to reflect in their field notebooks about the evidence and what they learned. This allowed time for students to process the information and reflect on what they experienced and how it influenced their knowledge and acceptance of evolution. On Day 1 of the short course, students were asked to create questions they wanted to explore regarding topics in evolution, and our activities were tied back to these questions so students could see that we were collecting evidence to help them answer their own questions.

For teachers or instructors interested in implementing a similar short course or lessons centered on evidence for evolution, most of the activities (Table 1) would be easily modifiable for 50-minute class periods. The longer videos were typically around 50–60 minutes; HHMI BioInteractive videos and activities could be done in 50-minute blocks. Bacterial culturing could be done in a regular classroom context as well (Carolina Biological sells kits specifically for this purpose).

Field trips to fossil parks would, of course, be dependent upon the availability of fossil parks in the area and ability to take students on field trips. We felt these trips were valuable for the students, and the students saw these as one of the highlights of the course. Although going to our university and seeing a current research project using Twitter was fun for the students, the goal of the activity was to highlight the range of knowledge and acceptance of evolution in the general public. A typical classroom may not have the extensive access to Twitter data that the university had, but this type of activity could be replicated by asking students to visit web pages selected by the teacher that exhibit different conceptions, misconceptions, and views around the theory of evolution.

○ Assessment Results and Findings

What effect did this course have on knowledge and acceptance of evolution?

We found significant gains in knowledge of microevolution and macroevolution, but no significant gain in evolution acceptance (Table 2). Gains for knowledge of microevolution were large (Hedges *g* indicates a gain of 0.87 standard deviations) and significant at the 0.01 alpha level ($t_{(20)}$ = 4.12, p = 0.001, g = 0.87, power = 97.4%). Gains for knowledge of macroevolution were moderate (Hedges *g* indicates a gain of 0.57 standard deviations) and significant at the 0.05 alpha level ($t_{(20)}$ = 2.50, p = 0.021, g = 0.53, power = 66.1%). Gains for acceptance of evolution were small (indicated by an increase of 0.30 standard deviations) but not significant ($t_{(20)}$ = 1.39, p = 0.18, g = 0.30, power = 26.2%). Due to the low sample size, statistical power was below 80 percent for knowledge of macroevolution and acceptance of evolution. This means there is greater than a 20 percent chance of failing to find differences when they should be detected. Hence we alsoaccompanied the *t*-tests with nonparametric tests. The Wilcoxon signed-rank tests for matched pairs corroborate the results of the *t*-tests, showing significant gains in knowledge of microevolution (z = 3.24, p = 0.001) and macroevolution (z = 2.62, p = 0.009), and no significant changes in acceptance of evolution (z = 1.60, p = 0.11) at the 0.05 alpha level.

How did cognitive and affective factors support growth in understanding of evolution in this evidence-centered educational intervention?

We then wanted to examine how the different cognitive and affective factors interacted and supported growth according to our framework, which suggests that gains in knowledge are facilitated by a combination of cognitive and affective factors (Figure 1). After controlling for grade level and prior content knowledge (MUM and CINS scores), we found a significant main effect of acceptance of evolution (Λ = 0.49, F = 7.18, df = 2 and 14, p = 0.007, ω^2 = 0.42, power = 87%), as well as a significant grade-by-acceptance interaction (Λ = 0.60, F = 4.65, df = 2 and 14, p = 0.028, ω^2 = 0.30, power = 69%) on gains in knowledge. These significant tests suggest that acceptance of evolution directly influences gains in knowledge through instruction on evolution (explaining 42% of students' gains), and that students' grade level moderates this influence (explaining 30% of students' gains).

Linear regression models for growth in knowledge of microevolution (F = 12.63, df = 5 and 15, p < 0.001, r^2_{adj} = 0.74, power = 100%) and macroevolution (F = 3.57, df = 5 and 15, p = 0.025, r^2_{adj} = 0.39, power = 79%) were significant at the 0.05 alpha level (Tables 3 and 4, respectively). Within the model for learning gains around microevolution, prior acceptance (β = 0.37, $t_{(15)}$ = 3.28, p = 0.005, ω^2 = 0.36, power = 87%) and the interaction between prior acceptance and grade (β = -0.04, $t_{(15)}$ = -2.53, p = 0.023, ω^2 = 0.24, power = 66%) were significant at the 0.05 alpha level. The effects of prior acceptance (β = 0.67, $t_{(15)}$ = 3.14, p = 0.007, ω^2 = 0.34, power = 83%) and the interaction of prior acceptance with grade (β = -0.07, $t_{(15)}$ = -2.63, p = 0.019, ω^2 = 0.26, power = 69%) were very similar for gains in knowledge of macroevolution.

Positive slope values for acceptance of evolution indicate that students coming into instruction with higher levels of acceptance generally made greater gains in their knowledge of both microevolution and macroevolution. Prior acceptance explains over 30 percent of the variation in students' knowledge gains on microevolution (ω^2 = 0.36) and macroevolution (ω^2 = 0.34). The negative moderating influence of grade level explains over 20 percent of the variation in students' gains (indicated by ω^2 values of 0.24 and 0.26, respectively). This indicates that prior acceptance had a greater effect on knowledge gains for students at the lower grade levels.

Valuing Evidence Over Authority

Our data support two general conclusions: (1) An extended evidence-based instructional approach successfully facilitates growth in knowledge of macroevolution and microevolution. (2) Both cognitive and affective factors lend support for knowledge of concepts in evolution. We found it interesting that acceptance of evolution exhibited highly similar positive effects on students' gains in knowledge of both microevolution and macroevolution (Tables 3 and 4). This seems to indicate that the affective domain plays a large part in students' ability and/or willingness to demonstrate greater knowledge of evolution after instruction. With regard to the theory of conceptual change (Posner et al., 1982), this result makes sense—students who accept evolution perceive less conflict with new ideas, and therefore find these new ideas more plausible and fruitful, leading to greater changes in ideas.

We found that prior knowledge of macroevolution supported students' learning of microevolution (Table 3), but that knowledge of microevolution did not support students' learning of macroevolution (Table 4). Students who come into instruction with more prior

Table 2. Significant gains in knowledge of microevolution and microevolution, and acceptance of evolution.

Construct	Instrument	Scale Range	Pre (*SD*)	Post (*SD*)	*p*-value	*g*
Microevolution	CINS	0–20	8.21 (3.29)	10.05 (3.76)	0.001	0.87
Macroevolution	re-MUM	0–22	13.32 (3.51)	14.68 (4.00)	0.021	0.53
Acceptance	MATE	20–100	71.00 (11.33)	73.98 (17.62)	0.18	0.30

Table 3. Factors supporting gains in knowledge of microevolution.

Parameter	β	SE_β	t	ω^2	power
Intercept	−24.70	8.85	−2.79*	0.28	74%
Grade	2.35	1.15	2.05	0.15	48%
MUMpre	0.37	0.08	4.62*	0.54	99%
CINSpre	−0.25	0.12	−2.01	0.15	47%
MATEpre	0.37	0.11	3.28*	0.36	87%
MATEpre x Grade	−0.04	0.02	−2.53*	0.24	66%

* $\alpha = 0.05$.

Table 4. Factors supporting gains in knowledge of macroevolution.

Parameter	β	SE_β	t	ω^2	power
Intercept	−44.58	16.73	−2.66*	0.26	70%
Grade	5.35	2.17	2.47*	0.23	63%
MUMpre	−0.29	0.15	−1.91	0.14	43%
CINSpre	0.24	0.23	1.03	0.004	16%
MATEpre	0.67	0.22	3.14*	0.34	83%
MATEpre x Grade	−0.07	0.03	−2.63*	0.26	69%

* α= 0.05.

knowledge are expected to better navigate new information and find new ideas more intelligible (Posner et al., 1982). In light of this expectation, it is interesting that prior knowledge of microevolution did not significantly support students' ideas about macroevolutionary concepts such as common ancestry, speciation, and deep time. These findings collectively suggest that many key concepts unique to macroevolution (deep time, common ancestry, speciation, and similarity of all life) provide a useful foundation for learning microevolutionary concepts related to natural selection, which drives home the importance of teaching macroevolution (Padian, 2010). However, the finding that knowledge of microevolution did not support learning of macroevolution suggests that some students may not understand how microevolution is related to macroevolution, and that students may even see these as completely separate processes. Students may understand and agree with microevolution but not with macroevolution.

If prior knowledge and acceptance does support instructional effectiveness, as is suggested by our theoretical framework and our data from this study, it may be unrealistic to see significant conceptual change from nonaccepting students during the initiation iterations of instruction in traditional authority-based classroom contexts, unless evolution is used as a framework for the entirety of biology coursework. If based in the context of authority, instruction will clash directly with competing ideas from larger sources of authority, including the student's family and church. Since encouraging our science students to reject these sources of authority is not realistic or desirable, we must replace authority with evidence in our instruction. With regard to the theory of evolution, gains in knowledge of macroevolution and microevolution rest on appealing not to students' sense of subservience, but to their sense of freedom and logic in interpreting a plethora of evidence from a variety of sources. In spending 11 days exploring evolution for both microevolution and macroevolution through a variety of activities, we found measurable gains in students' knowledge as they were able to observe and interpret natural phenomena that can only be explained by the theory of evolution.

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