Nelson *et al. Evo Edu Outreach (2019) 12:6*
https://doi.org/10.1186/s12052-019-0100-7

Evolution: Education and Outreach

CURRICULUM AND EDUCATION

Open Access

The nature of science as a foundation for fostering a better understanding of evolution

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Abstract

Misunderstandings of the nature of science (NOS) contribute greatly to resistance to evolutionary theory especially among non-scientific audiences. Here we delineate three extended instructional examples that make extensive use of NOS to establish a foundation upon which to more successfully introduce evolution. Specifically, these instructional examples enable students to consider evolutionary biology using NOS as a lens for interpretation of evolutionary concepts. We have further found, through our respective research efforts and instructional experiences, that a deep understanding of NOS helps students understand and accept the scientific validity of evolution and, conversely, that evolution provides an especially effective context for helping students and teachers to develop a deep understanding of the nature of science. Based on our research and instructional experiences, we introduce six key factors necessary for enhanced instructional success in teaching evolution. These factors are: (1) *foster a deep understanding of NOS*; (2) *use NOS as a lens for evolution instruction*; (3) *explicitly compare evolution to alternative explanations*; (4) *focus on human evolution* (where possible); (5) *explicitly recognize the power of historical inference* and (6) *use active, social learning*. Finally, we elaborate and ground these key factors in supporting literature.

Keywords: Evolution, Nature of science, Instructional success

Background

In many nations, high percentages of otherwise educated people misunderstand and reject evolution. We suggest that this rejection and misunderstanding is most directly the result of traditional, didactic teaching strategies and of a failure to effectively teach the nature of science (NOS) or, even, commonly, of a failure to teach NOS at all. Further, secondary and, especially, postsecondary science teaching often ignores strong evidence on diverse ways to make instruction much more effective, not just on the importance of NOS (e.g., Freeman et al. 2014; Handelsman et al. 2004, 2006; Labov et al. 2009; Singer et al. 2012; Wieman 2014. For evolution: Alters 2005; Alters and Nelson 2002; Nelson 1986, 2000, 2007, 2008, 2012a, b; Scharmann 1990, 1994a; Sinatra et al. 2008; Smith and Scharmann 1999).

We acknowledge that public misunderstanding of evolution is partly due to conservative religious influences and dubious political motivations (e.g. Mazur 2004; Ranney 2012; Rissler et al. 2014; Wiles 2014) but find that trying to deal with those issues directly rather than framing them through the lens of NOS is much less constructive than our focus here on seeking improved instructional practices and more effective learning. Importantly, Ranney's (2012) review of the extra-scientific reasons many Americans reject evolution leads to suggestions, discussed below, of ways to make instruction more effective.

We did not begin our efforts to teach evolution by simultaneously providing a firm foundation on the nature of science. Rather, we gradually understood that much more emphasis on NOS was needed. Ultimately we came to two initial insights: (a) adequately understanding evolution at all levels requires that students have a strong foundation in NOS; and (b) evolution provides a context

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in which the nature of science is especially easy to learn because of students' engagement and of the diverse kinds of evidence that must be brought to bear (including experimental; comparative molecular, structural and behavioral; and historical).

Among the present authors, Flammer began this process earliest. He taught high school biology from 1960 to 1997 and was an early adopter of the Biological Science Curriculum Study Blue Version, *Molecules to Man* (BSCS 1963). His awareness of the importance of teaching the nature science was focused by major efforts to foster reform in high school science (Project 2061 1989; National Research Council 1990). These syntheses emphasized the lack of basic understanding of the nature science in our population and the usual lack of effective NOS instruction at all levels. In Flammer's classes, science illiteracy was most obvious when evolution was introduced. Some students each year asked him to teach "Creation Theory" or "Intelligent Design" as viable alternatives. Flammer explained that those ideas weren't scientific, why they weren't scientific, and, therefore, why they couldn't be properly considered along with evolution. But those points were usually lost in the somewhat confrontational emotion of the moment and typically fell on deaf ears. Consequently, he began to introduce NOS as his first unit in the year, with no mention of evolution. His evolution unit was introduced a month or so later. This proved to be much more effective than introducing NOS within the evolution unit. There was less confrontation and more willingness to understand evolution.

Beard taught high school biology from 1961 to 65 and also used the BSCS Blue Version, *Molecules to Man* (1963). This curriculum introduced inquiry learning in chapter one and used evolution as a theme throughout (most other texts left it to the end of the book where it could easily be omitted). Beard then earned her doctorate and was hired as a science educator in the College of Science at San Jose State University, where she completed her career. She continued to hone her NOS activities in an upper division college level general education science course and in methods for secondary science teachers and supervised pre-service high school biology teachers. Beard and Flammer met in the 1970s when some of her pre-service biology teachers interned in his classroom.

Nelson taught undergraduate and graduate courses on evolution and ecology and did research in these fields at Indiana University in Bloomington from 1966 to 2004. He focused most heavily on NOS in a senior course on evolution and in a graduate course on Community Ecology. He has applied the NOS ideas discussed here to environmental literacy (Nelson 2010a) and to the illusion of a tradeoff between content and critical thinking (Nelson 1999). He has also addressed key pedagogical changes needed for biology (Nelson 2010b) and for college teaching generally (Nelson 2009, 2012a).

Beard, Nelson, Nickels and others first met on a teacher in-service committee of the National Center for Science Education (NCSE) supported by the Carnegie Foundation where they began planning summer institutes for in-service biology teachers. Our second proposal to the National Science Foundation (NSF) was accepted in 1989 for evolution and the nature of science institutes conducted at Indiana University (Principal Investigator—Craig E. Nelson).

Scharmann taught high school biology before returning to school for his doctorate in 1982. There he studied evolution with Nelson who also served as one of his graduate mentors. He reports: "my earliest attempts at teaching evolution were well intentioned. They were also naïve and quite inadequate. I did not account for student resistance, administrative pressures, or questions from parents or local political leaders. I sought… advice from experienced biology teachers in my own school on how to more appropriately handle the instruction of evolutionary biology. The advice I received was equally well intentioned—'Just teach the concepts without ever mentioning evolution' or 'save evolution for the last unit in the academic year, then you can avoid all of the difficult questions.' However sincere, the advice was inadequate, intellectually dishonest, and did not appropriately characterize the power of scientific theories to explain, predict, and serve as a lens by which to pose and answer scientific questions."

"With additional insights gained during my doctoral program, I revised my approach to teaching evolution to recognize that science depends of necessity on degrees of uncertainty, the development of criteria, and the use of criteria by which to make decisions in the face of uncertainty. With repetition of results, recognition of patterns in collected evidence, and supported by corroborative lines of evidence, scientific theories provide us with tools by which to make decisions. I still needed to learn how to make my new insights developmentally appropriate for novice science students." (For a detailed account of this narrative and the inferences garnered see Scharmann 2018).

More generally, we have individually and together been emphasizing the relationship between understanding evolution and understanding the nature of science (NOS), and, more generally, utilizing evidence based pedagogical approaches. We have done so in various educational contexts including undergraduate courses and pre-service and in-service teacher preparation. In each case, more effective evolution instruction has been the goal with deeper understanding of nature of science serving as the foundation for instruction.

The most sustained of our efforts was Nelson's undergraduate course on Evolution (1967–2003). The central premise of his approach became that evolution can be understood clearly and deeply only when framed by the nature of science (Nelson 1986, 2000, 2007, 2012a, b. Nelson 2000 is an invited how-to-do chapter written specifically for high school teachers). He found that a NOS-rich approach increased acceptance of evolution and general critical thinking skills (Ingram and Nelson 2006, 2009).

The first major collaborative efforts among some of us were NSF supported *Evolution and the Nature of Science Institutes* (ENSI 1989–1998) for experienced high school biology teachers. Our approach was summarized in "the nature of science as a foundation for teaching science: evolution as a case study" (Nelson et al. 1998; see also Beard 2007; Flammer et al. 1998; Nickels et al. 1996). The core of the approaches used in ENSI is a series of hands-on lessons on NOS, evolution and their connections. Most participating teachers said they came to get current ideas in evolution but instead found the deeper understanding of NOS to be transformative. In their teaching, they reported greater emphases on NOS, on evolutionary processes and on conceptual understanding (rather than just imparting facts). Emphasizing the nature of science made an immense difference. Each of us used and refined the developing ENSI materials in our own classrooms.

At the close of NSF support, we instituted *ENSIWEB*: Evolution/Nature of Science Institutes (Flammer et al. 1998). Larry Flammer, an ENSI-trained biology teacher, served as web master taking the lead in selecting and designing new lessons, articles and other materials of interest to teachers, materials that are especially useful for both high school and college biology. Flammer developed a teaching unit for high school biology on the Nature of Science, using many ENSIweb lessons (Flammer 2012). Seeing the importance of basing earlier science instruction on the nature of science, he also developed *Science Surprises: Exploring the Nature of Science* (Flammer 2014, 2016) an electronic text supplement that makes the ENSI approach to NOS very accessible to students in grades 7–10.

Scharmann designed institutes similar to ENSI entitled *Nature of Science and Premises of Evolutionary Theory* (NOSPET 1989–1991), again for experienced high school teachers of General Biology (Scharmann and Harris 1992; Scharmann 1994b). Smith and Scharmann later began a collaboration based on ideas from NOSPET but focused on preservice teachers taking an introductory biology course. NOS activities promoted the use of a "more scientific to less scientific" continuum that allowed preservice teachers to negotiate a "place to stand" as they progressed in their understanding that a scientific theory, such as evolution, can provide greater explanatory power, predictive capacity and ability to solve scientific problems than can rival explanations (Scharmann et al. 2005; Smith and Scharmann 1999, 2008). Scharmann and Butler (2015) used exploratory journals to foster a deeper understanding of the nature of science in conjunction with potentially controversial topics. Students were encouraged to make any statements they wished in their journal entries without the fear of losing points while instructor feedback encouraged students to apply the nature of science (e.g., evidence considered and inferences based on observations) and intervened to correct misconceptions concerning NOS and evolution. Students became more sophisticated in using evidence from lab activities to support their arguments as the semester progressed.

Ha et al. (2015) recently reviewed the studies of short-term professional development for teachers that have focused on evolution. As a result they implemented a carefully designed course, parallel to our efforts in key ways, and documented persistent effects similar to those we found less formally. As their treatment is so rich and recent, we are omitting for this context further review of similar professional development efforts.

Re-conceptualizing and applying the nature of science in teaching evolution

Whenever we have taught evolution, whether to undergraduate science students or to pre-service or in-service teachers, we have found that fostering a deep understanding of the nature of science is crucial. This is due to the complexity of the evidence for evolution, to the many misconceptions that are common and to the culturally fostered skepticism to accepting the conclusion. Further, teachers as well as students typically have only a partial understanding of the nature of science and how it might apply to any complex science. Hence, a through reconceptualization of the nature of science is essential to developing an adequate understanding of evolution as well as to considering an acceptance of its scientific validity. Experienced high school teachers of General Biology who participated in our efforts (especially in ENSI and NOSPET) reported substantial changes in how they taught both evolution and the nature of science (Nelson et al. 1998; Scharmann and Harris 1992).

Success both with students and teachers rests, in our experience, on a conjunction of six key factors. We strongly recommend each of these individually to faculty and other teachers and to those who are working with experienced or pre-service teachers and, especially, urge using several or all of them together.

1. *Foster a deep understanding of NOS*. It is essential to foster a deep reconceptualization of the nature of sci-

ence. Specifically, both students and teachers need to reexamine their usual emphases on the steps of the scientific method and on scientific knowledge as largely true and then replace them with more realistic emphases on the degrees of uncertainty and the comparative basis of scientific knowledge.

2. *Use NOS as a lens for evolution instruction*. This reconceptualization of NOS must be used to enable an assessment or reassessment of the strength both of the support for evolution and of its explanatory and predictive power.
3. *Explicitly compare evolution to alternative explanations*. These strengths are not nearly as evident unless alternatives are directly compared whenever the educational context allows. Paradoxically, we found that comparing evolution with non-scientific alternatives, including young-earth creationism and intelligent design, on the bases of NOS, evidence and consequences makes evolution seem less challenging to fundamentalist religion, as it is no longer a confrontation of dogmas. This approach allows students to focus first on understanding NOS and the science and only later on deciding how far to go in accepting evolution.
4. *Focus on human evolution (where possible)*. A focus on humans whenever possible is crucial (Nickels 1987; Pobiner 2016). Using humans takes advantage of our species inherent interest, allows a more engaging focus on misconceptions (about both NOS and evolution) and focuses on the species, humans, that many people find most difficult to accept as a product of purely natural processes.
5. *Explicitly recognize the power of historical inference*. It is important to emphasize that although evolutionary science includes strong historical elements, strong historical inferences can be based on present evidence when used to make and test predictions, often when combined with corroborative observational evidence [see Instructional Example 1, Topic 4 below; for additional context also consult Bedau and Cleland (2010)].
6. *Use active, social learning*. Active, social learning is essential throughout. Without it content is often misunderstood or discounted and misconceptions typically remain unchanged. Further, in direct consideration of secondary school biology, it is important to have teachers find, present and, especially, directly participate in activities and assessments that were appropriate for use in their own classrooms. This is central in fostering a transformation of their teaching in both content and pedagogy. We found that this approach led teachers to use much more extensive and accurate presentations of both NOS and evolution. This key factor has been reinforced, more recently, by Glaze et al. (2015).

We will spend much of the remainder of this article on ways to use these key factors by delineating three extended instructional examples. The first example features the work of Flammer (independently and in collaboration with Beard and Nelson). The second example highlights the contributions of Scharmann (independently and in collaboration with Mike U. Smith). The third example focuses on the NOS pedagogy developed by Nelson for teaching evolution.

Instructional example 1: NOS as background for evolution in high school biology

The first major collaborative efforts among some of us (as noted above) were the National Science Foundation (NSF) supported *Evolution and the Nature of Science Institutes* (ENSI, 1989–1997). The original institutes were 3-week residential programs for experienced high school biology teachers. Beginning in 1991 another concurrent 3-week program was added to train selected ENSI alumni as "lead-teachers" to present 2-week "Secondary" versions of ENSI or SENSI (informally dubbed "Son of ENSI" by the participants). Flammer was an ENSI alumnus and was selected as a SENSI lead teacher. Upon retirement in 1997, he became the developer of ENSIWEB—converting materials that teachers had collected and developed in ENSI sessions. Once the format was established, he reworked the lessons and posted them; as comments came in and/or new materials were found they were modified. Larry was the ENSIWEB Webmaster from 1997 until his death in December 2017.

This example of the ENSI case for NOS as background for evolution is Larry Flammer's. He started his biology class with a NOS unit. About a month later he began teaching evolution. Below are the content and sequence of topics from the background unit.

Topic 1: awareness of NOS. Lesson: misconceptions survey

As an engaging first step, students should be made aware of some of the more common misconceptions about NOS. Of special concern are misconceptions about NOS that are revealed in typical anti-evolution arguments. On the first day of class, students are given a "Science Survey" quiz (see Flammer et al. 1998) listing statements that reflect some important NOS misconceptions (e.g., Theories that are repeatedly tested become laws; if humans descended from related primates, why are those primates still in existence; legitimate science is performed empirically through exclusive use of controlled experiments). Students are asked to indicate (with "agree" or "disagree) how they think a scientist might answer for each statement, thus assessing their understanding of NOS. The tests are machine scored, generating an item analysis. The next day in class, items that were missed by the most students are shared with the class. This establishes that there is, indeed, widespread misunderstanding of just what science is, what it can do, how it does it, and what it cannot do. At this point, announce to the class "our job is to repair those misconceptions." Later, this same approach is used with an evolution concepts survey.

The best way to foster a deep understanding of NOS is for students to engage in interactive experiences with examples of what science is and what science is not, what it can do and what it cannot do. Reflection and discussion of those experiences should reveal specific elements of NOS.

Topic 2: the realm of science. Lesson: "sunsets, souls and senses"

This lesson provides a list of some 30 phenomena (e.g., atoms, beauty, angels, tides, Santa Claus, weather, etc.). Students consider and discuss (in teams of 3–4) whether each item could or could not be studied by science and why or why not. Teams share their conclusions in a general class discussion while the teacher moderates. Out of that comes an awareness of several points that differentiate topics in science from those outside the realm of science. Then each team opens an envelope filled with a number of terms and short phrases on strips of paper. The teams consider each term or phrase, list it as "Science" or "Not Science" and explain why. In terms of a fundamental characteristic of NOS, this processing effectively illustrates that science has limits.

Two aspects of "science has limits" are especially important for fostering an engagement with evolution later. One of the most important discoveries from this lesson is that science cannot use supernatural powers as an explanation for any natural phenomenon, a basic rule of science. Make it clear that this is not arbitrary—there is a good reason for this rule. Testing is a fundamental requirement for the study of any scientific explanation, but any test of a supernatural explanation would be pointless, since a supernatural power could produce any outcome. Therefore, supernatural explanations cannot be definitively tested or potentially disproven. This rule will be most helpful later when introducing evolution, where some students may ask why we can't consider "Creation" or "Intelligent Design" as reasonable alternatives to evolution. Merely reminding them of the "no supernatural explanations" rule for science (often recalled by others in class) is sufficient to bypass that discussion and return the focus to the science of evolution and its naturalistic explanations for diversity in the living world.

A second aspect of "science has limits" is a rule saying that science can only address phenomena of the natural world, not the supernatural. If we want to study a supposedly supernatural phenomenon scientifically, we must use the working assumption that it's *not* supernatural. This limitation of the realm of science is an important realization. It means that science must remain neutral regarding the supernatural. Science can neither prove nor disprove the existence of anything supernatural. For that reason, science cannot be atheistic, in contrast to the anti-evolution assertions that scientific views are atheistic. This leads to the realization that science can be seen as one of several ways we have for understanding the world we live in. Philosophy, religion, politics, aesthetics, and personal experiences are other ways of knowing. Each of these has its appropriate realm of application and its own rules. Many or, perhaps, most people find ways to accommodate those different perspectives in their lives, properly applied to their appropriate realms. Where contradictions seem to exist individuals can learn to find ways to reconcile them, most importantly by realizing that different ways of knowing are looking at different aspects and follow different rules.

A useful illustration for this is to show a view of your school seen from the street, then one from an airplane or satellite. Although these show the same thing, we get different information from those different views: different perspectives of the same reality. Neither view is "wrong" nor "right," they are just different. A brief discussion of this can go a long way toward removing animosity against science (or selected scientific concepts) where it seems to conflict with different beliefs or politics.

Topic 3: "facts" and the processes of science. Lesson: mystery boxes

Another common misconception is that science focuses on facts and absolutes. An excellent lab experience involves each member of a team of students taking turns trying to figure out what's inside one of a set of "Mystery Boxes" puzzles (Beard 1989). The boxes are sealed shut and can't be opened. By tilting, and feeling changes in balance, and hearing signs of sliding and/or rolling, individuals can get a sense of what might be inside the box, including any moving object(s) and/or barrier(s). Then, without realizing it, they are testing their tentative ideas (hypotheses) by predicting what should happen when they tilt it a certain way, then tilting it that way. They also share their ideas, and have other team members check them out, sometimes modifying early ideas. Finally, they "publish" the results by sketching on the board (for all to see) what they have concluded must be in the box. Are they certain of this? Not really, but they've typically gone through different levels of possibility to high probability of their conclusions, but this is not certainty. It is particularly important for fostering a deeper understanding of NOS to insist that the students never see or otherwise find out exactly what's inside their box, just as scientists often never really know with certainty the answer to all their questions. Scientists will probably never know with the certainty that comes from direct observation what the center of Earth is composed of, but they have used a variety of clever clues to give them a pretty good idea, probably close to reality, but not with absolute certainty. Likewise, we know that living processes (i.e., protein synthesis) depend on transcription and translation using a largely universal genetic code even if the origin of that code is uncertain.

More subtle, but no less important, is discriminating between what we observe (with our senses) and what we infer from those observations (how our brain interprets those observations). Working with the "Mystery Boxes" lesson helps students to realize how we automatically slip from observations to interpretations and analyses; in other words, seeing is not knowing (Khishfe and Abd-El-Khalick 2002). Awareness of those functions helps scientists to be more objective and purposeful in their studies. It is also important to use the exercise to help participants see that science is a social activity and that social collaboration can often increase the strength of scientific inference and, as Ford (2012) emphasizes, result in increased "sense-making."

The other side of the "uncertain" or "tentative" nature of science is the fact that scientists have accumulated very high confidence in their understanding of many phenomena. New explanations are tentative, but repeated testing and successful applications can make those explanations more robust and durable. Science works and leads to increasingly secure knowledge. But when students read that scientific knowledge can change (get better) with new information, especially when the word "theory" is attached (which they misunderstand as a "hunch"), they are tempted to think that anyone's personal opinion about the phenomenon is just as good as any scientist's [see Larochelle and Desautels (1991) for additional context]. Thus, in addition to emphasizing the tentativeness of science, teachers must also emphasize the growing durability of scientific knowledge and to all of the achievements of science: in health and medicine, space, environment, weather, agriculture, etc. Scientific knowledge is growing rapidly, getting better every year. But every year, many more questions are raised, making for an exciting career potential for any student who is particularly curious about the natural world and a series of important developments for everyone to follow.

Topic 4: questioning the past. Lesson: great fossil find or checks lab

As early as possible, teachers should engage their students in an experimental inquiry: trying to answer a question about the natural world by doing an experiment. This could be a simple study of a pendulum: What determines the rate of a pendulum's swing: its length, its mass or both? Or it could be to find out how slightly salty water affects the germination of oat seeds (as we anticipate an increasing inundation of coastal lands from the seas). Or why is the T-illusion an illusion?

But students must also explore a question about the past, using strategies of historical science (Beard 2007). Alternatives that require students to collect, analyze and interpret clues about the past include "The Great Fossil Find," "The Checks Lab," or the "Crime Scene Scenario" (Flammer et al. 1998).

The Great Fossil Find simulates the discovery of a few fossil fragments in the field (paper cutouts taken at random from an envelope), from which teams must try to figure out what kind of creature died there. Finding additional fragments in return "trips" sheds more light on the reconstruction. Teams compare notes and try to select the most likely reconstruction. But they never really learn with certainty what the animal was.

The Checks Lab is similar, in that each team randomly picks out three personal checks from an envelope (representing a few checks found in a drawer in an abandoned house). Looking at clues, like dates, who the checks were made out to, for how much, and who signed, each team tries to figure out a story line that could explain the checks they have. Then they "find" a few more checks, and modify their story accordingly, etc. Any Crime Scene/Forensics lesson would also serve as an engaging example of "historical" science, showing students that science can, indeed, study the past by examining clues. Science doesn't have to be experimental. A tentative explanation for clues can lead to predictions of additional clues to look for. Searching for those clues provides a test for the explanation.

Topic 5: truth and bias. Lesson: false assumption stories

Everyone has biases, even scientists! For that reason, science follows certain protocols that effectively reduce bias. Most research these days involves two or more scientists working and publishing on a particular problem, so biases tend to be mutually cancelled. Responsible research must be published in professional peer-reviewed journals, where each report is critically assessed for methodology, content, conclusions and limitations. And published findings are typically reexamined in further research. Because of this, science tends to be self-correcting, unlike many other ways of knowing.

An engaging exercise is for students to read a brief story with a peculiar twist and try to figure out what "false assumptions" they are making. This gets students thinking creatively and "outside the box." A collection of "False Assumption" stories is available from ENSIWEB, with strategies for presentation and discussion. These experiences make clear to students that we all have our biases.

Topic 6: integrating and applying NOS throughout the course

In addition to introducing the course with an in-depth study of the nature of science, there are frequent opportunities throughout the course for students to refresh and reinforce their NOS knowledge (Flammer 2012, 2014). Conversely, these opportunities are also points where their knowledge of NOS can facilitate and deepen their understanding of evolution and other aspects of biology. With every topic, examples of different NOS elements can be seen. You should reward students for recognizing those NOS elements (simple recognition, dramatic recognition, or, if you must, bonus points).

Note that this same sequence is applicable to general science and to other sciences and can fit courses from middle school to college.

Instructional example 2: developing a continuum from more to less scientific (the demarcation debacle)

Scharmann designed institutes similar to ENSI entitled *Nature of Science and Premises of Evolutionary Theory* (NOSPET 1989–1991), again for experienced high school teachers of General Biology (Scharmann and Harris 1992; Scharmann 1994b). Smith and Scharmann later began a collaboration based on ideas from NOSPET but focused on preservice teachers. Scharmann and his collaborators proposed that science teachers should learn to describe the nature of science using a continuum of less to more scientific depending on how closely an individual scientific claim met established criteria to justify it as more scientific in comparison to other alternatives (Smith and Scharmann 1999, 2008; Scharmann et al. 2005).

To initiate this instructional approach, present eight knowledge claim statements (see Table 1) and ask students to individually order these claims from least to most scientific (without providing them with any criteria by which to make decisions). Once students complete the task as individuals, ask them to work in pairs (or larger groups) to compare their individual results and come to consensus on a final order for the eight statements (again, without the benefit of any predetermined criteria).

Student to student interaction in these two phases is typically quite active as they pursue consensus through discussion, argumentation, and personal persuasion. Once consensus is reached by pairs or larger groups, ask students to display their final order on a white board in order to compare group results. This phase of the instruction involves teacher to student interactions in which students begin to see patterns across groups. Two statements (i.e., D and H) are readily viewed as the most scientific, while groups usually disagree on the placement of the other six. When asked how they made final decisions on those six less scientific statements, students offer explanations involving whether the claim could be observed, predicted, measured, tested, repeated, etc. In other words, students develop and apply criteria by which to make decisions—they have developed a set of NOS criteria by which to judge statements as more or less scientific.

The culminating task, once students are in possession of a set of criteria, is to individually apply their class-developed criteria (and additional criteria introduced through further readings and class discussions) to place fields of study in relation to one another on the less to more scientific

Table 1 Knowledge claim statements

A	If you break a mirror, you will have 7 years of bad luck
B	The earth is flat. Anybody can see that!
C	Humans have a soul. I believe this because it says so in the Bible. The soul is what separates us from animals
D	All living things are composed of one or more cells. We know this because every living thing examined to date has been found to be composed of one or more cells
E	Taking vitamin C prevents the common cold. Linus Pauling, the Nobel laureate who discovered the structure of vitamin C says it does
F	There is a God. I know this because I can feel Him in my soul and because I depend upon Him every day
G	If you dream of tea, someone will die. I have always heard this, and it actually happened to me one time
H	The rate of acceleration of all falling objects on earth is constant. Two spheres of identical diameter and volume are dropped from the top of a building; one is made of steel and the other made of a plastic polymer. They both accelerate at the same rate (32 ft./s^2) and hit the ground at the same time

continuum and to write a short explanatory essay to justify their placements. The fields of study are:

- *Umbrellaology* (Somerville 1941) is a classic NOS exercise in which the author presents data collected concerning umbrellas. The data reflect correlations for selection of umbrella color with gender or age, the predicted number of umbrellas one might expect per household or the preferred diameter of umbrella based on geographical region of the world, etc. The author ultimately requests the reader to decide whether umbrellaology represents a science.
- *Intelligent design (ID)* represents, according to Peterson (2002), an explanation for specific biological complexities (e.g., blood clotting, the structure of the human eye, the rotor mechanism of a bacterial flagellum) being irreducibly complex and therefore intelligently designed.
- *Evolution* as presented by Mayr (1991) is an explanation for all biological diversity resulting from change in organisms over time due to natural selection and modification with descent.

The resulting justification narratives provided by students strongly reflect the utility of using NOS criteria to conclude that evolution is the most scientific since it meets more criteria than either umbrellaology or ID. Students argue in their own words that evolution predicts, can be subject to testing, yields extensive observations, and provides a lens for explaining thorny observations (such as why inherited eyesight in humans has progressively deteriorated in recent centuries). They also argue that umbrellaology explains and predicts but does not solve scientific problems; and argue that although ID may be perhaps an appealing personal explanation, it offers little predictive capacity, cannot be readily tested and does not solve scientific problems. From reading multiple justification narratives over a 5-year period, we concluded that the acceptance of evolution among students improves after they (i) possess an understanding of NOS, (ii) learn to recognize and apply appropriate criteria by which to make decisions, and (iii) learn to justify given claims as more scientific when compared to rival statements/less scientific explanations, despite for some students the personal appeal of a claim like ID (Smith and Scharmann 2008).

Instructional example 3: using nos to foster the understanding of evolution and evolution to foster a deeper understanding of nos in a college course on evolution

We will next address a broader range of pedagogical strategies for using NOS concepts to foster a deep understanding of evolution and vice versa. Evidence is growing that combining a focus on NOS with a focus on evolution is particularly effective and is one emphasis (among others such as essentialism, teleology, and direct causal schema) across multiple chapters in Rosengren et al. (2012) as obstacles to learning evolution. Here, we describe NOS focused strategies that we have found to be particularly effective. These strategies are largely those that Nelson developed from 1967 to 2003 and applied in his course on evolution for biology majors (Nelson 1986, 2012a, b).

Group 1. The realm of science: contrasting scientific findings to topics that are not scientific

The first two of our extended instructional examples, above, illustrate ways to implement this strategy:

- NOS concept: what science is and what it is not.
- NOS concept: science and nonscience are best seen as a continuum.

Group 2. Scientific argumentation and the strength of evolution

Scientific reasoning is a set of procedures for comparing and testing alternative ideas and judging some to be "better," procedures that explain how science can be fundamentally uncertain yet quite useful and reliable. It is important to help students understand the overall strength of evolution. Specifically:

- NOS concept: science finds, summarizes and explains empirical patterns.

It may help to use the distinction between showing regular empirical patterns (empirical laws) and scientific theories in which empirically-grounded, causal explanations have been established. Science establishes empirical patterns (planets orbit the sun in irregular ellipses) and tries to provide causal explanations that explain those patterns (planetary orbits reflect an interaction of inertia with warped space). Religion does not help us choose among alternative patterns or find the causes. Design fails as an explanation because it could apply to any pattern (rectangular orbits, for example). Contrasting *scientific explanation* with *attribution to a supernatural power* can help students understand both the nature of science and the limits of religion in thinking about the natural world as well as the limits of science about thinking about the supernatural world.

A key aspect of NOS is the role of providing connections between patterns and explanations. Copernicus summarized patterns of planetary movement. Newton provided the causal explanation, replacing attribution to direct action by God with explanation by the action of natural laws.

Darwin's role was parallel. Paley summarized a major empirical pattern (organisms have complex adaptations) and attributed this pattern to design by a creator (which could apply to any pattern and therefore explains none of them). Darwin explained the origin of these adaptations using natural selection acting on heritable variation (which can only explain features that increase fitness). Again, attributing a pattern to God was not a substitute for a scientific explanation.

- NOS concept: strong scientific theories are usually supported by multiple, independent lines of evidence.

Darwin (1859) showed how evolution was supported by: Paley's adaptations, Linnaeus' natural groups, key patterns in biogeography and paleobiogeography, and other aspects of biology. This confirmation by multiple independent lines of evidence was Darwin's central argument for evolution. Students need to understand multiple confirmations as a core aspect of scientific argumentation and as the key to how evolution explains all of biology.

Human evolution provides an especially compelling example of multiple lines of confirmation. Much of the intuitive resistance to evolution centers on human evolution for psychological reasons, reasons of personal incredulity, or reasons centered on perceived consequences (Evans et al. 2010) and for theological reasons (Nelson 1986, 2000). Hence, it is important to use humans and other primates to illustrate many aspects of evolution (Nelson and Nickels 2001; Nickels 1987; Nickels and Nelson 2005; Pobiner 2016; Wilson 2005, 2007). Broadly incorporating humans into the classroom story also makes evolution more interesting.

The evidence for human evolution is very strong. Multiple lines of compelling evidence link us to other great apes [skulls, chromosome structure, chromosome fusion, pseudogenes, etc. (e.g. Flammer et al. 1998)]. Good use can also be made of excerpts on such topics as the evolutionary-developmental explanations of the *Quirks of human anatomy* (Held 2009) and Darwinian medicine (Gluckman et al. 2016; Stearns and Medzhitov 2015; Taylor 2016). As a powerful example, engagement is particularly strong when students do small group comparisons of resin replicas of skulls of human, apes and related fossil forms (Flammer et al. 1998; Nelson and Nickels 2001). Students will long remember such compelling experiences, along with the associated NOS concepts on how science generates durable knowledge.

- NOS concept: strong scientific theories rest on clear causal explanations.

The strength of a scientific theory rests both on multiple confirmations and on the completeness of its causal explanations. Darwin had three key processes: natural selection, the tendency of organisms to resemble their parents and other ancestors, and the tendency of individuals to vary somewhat from their relatives. His causal explanations for resemblance and variation were inadequate because he had incomplete and erroneous ideas of how heredity works. Now DNA provides a deep causal explanation for heredity that explains why groups of organisms that share a common ancestor *must* resemble each other and *must* differ from groups that do not share that ancestor. Similarly, molecular and comparative biology have documented causes and patterns for multiple modes of speciation (Marques et al. 2018; Coyne and Orr 2004).

- NOS concept: scientific ideas are known with various degrees of confidence but always remain tentative.

To help students master NOS, and to keep ourselves honest, we need to distinguish conclusions supported by strong evidence from those that are merely speculative (e.g., Ranney 2012). Viewed broadly, evolution encompasses two areas where knowledge is generally well supported that separate three "origins" questions where scientific ideas are speculative and evidence is slim or absent (Nelson 2000). The two well-supported areas encompass (i) the physical and chemical processes related to the history of the universe and (ii) the processes and history of biological evolution. Ideas are much more speculative on the origins of the universe, of life and of consciousness. This distinction does *not* claim that that we will not ultimately be able to show naturalistic origins for more of these. Rather, it simply acknowledges that we do not now have secure knowledge of how they happened.

Group 3. Additional NOS based pedagogical tactics to foster greater understanding and acceptance of evolution

To help students and teachers better understand the nature of science and biology, we can help them articulate and compare ways of integrating science with religious or other frameworks (c.f. Ranney 2012). This strategy addresses problems discussed both herein, and by Brem et al. (2003), Evans et al. (2010), Nehm and Schonfeld (2007), and Nelson (1986, 2000, 2007).

The ideas in this section have two goals beyond fostering a deep understanding of the nature of science and evolution: (1) to make explicit the failure of creationist arguments when considered as science and (2) to facilitate change towards more fully scientific positions by helping students and teachers bridge the stark gap that many see between anti-scientific creationism and anti-religious evolution (Ingram and Nelson 2006; Nelson 1986, 2000, 2012a, b; Scharmann 1994a, 2005; Scharmann et al. 2005; Wilson 2005, 2007).

- Pedagogical tactic: understanding should precede acceptance or belief.

Explicitly announce at the start of a course that the goal in studying evolution does not depend on accepting evolution. Stress that instead the students' tasks are to understand how evolution is central to biological explanation and to understand why most scientists evaluate evolution as truly great science. Asking students to decide whether to accept evolution before they understand these things is premature and makes it harder for them to understand NOS and the critical thinking core of scientific reasoning. Once they understand them, questions of connections to other areas will arise spontaneously. Ranney (2012) emphasized the importance of training teachers to "explicitly evidentially and epistemologically compare evolution with creation" in their classrooms. It would serve us well if college faculty were also prepared to do this (Shtulman and Calabi 2012).

- Pedagogical tactic: the NOS can be better understood through student discussions analyzing creationist arguments.

Biochemist Bruce Alberts, former President of the US National Academy of Science, has argued that intelligent design should be included in college science courses in order to better teach the nature of science (Alberts 2005). How can this be done? One way is to provide students with appropriate resources and having them study and discuss them. Having students read Behe's (1996, 2003) canonical presentations of intelligent design together with counter arguments (Miller 1999, 2003; Peterson 2002) should be a powerful strategy in parallel to Verhey's (2005) use of other readings.

More generally, we can use creationist readings pertinent to any of the points addressed by the preceding strategies. Gould's (1985) essay, "Adam's navel," included key quotes from a pre-Darwin scientist (Gosse) arguing that the fossil record was created intact to give earth the appearance of great age, an untestable argument. Gould provided a very sympathetic refutation. Discussions of Gould's article guided by study questions were quite successful in helping students understand that testable predictions are at the core of science, a key NOS concept.

Gould's later edited volume (Gould 1993) included descriptions of key fossil assemblages and depositional environments. Discussions of how these assemblages might be well explained by evolution and not by flood geology helped students understand geological age, the abundance of fossils, the ecological coherence of the fossil assemblages, and the fossil evidence of macroevolution as well as the scientific vacuity of flood geology. The NOS concepts on the roles of evidence and predictions are central to this exercise and are made more memorable thereby.

Alternatively, one can use an exercise to help students build a meaningful sense of deep time and see how the different classes of vertebrates emerged tens of millions of years apart, with each new class adding new traits modified from earlier ones (Flammer 2008). To make the contrast explicit, ask students: "What pattern of origins (simultaneous or sequential) would be expected from the creation story?" Usually, most say that we would expect all forms of life appearing at about the same time, independent of each other. This expectation clearly contrasts with what we actually find in the fossil record.

- Pedagogical tactic: emphasize that many scientists and theologians argue that there is no necessary conflict between science and religion and that there is a range of views on the relationship between science and religion.

Many students who may see a chasm between creationism and evolution have never considered intermediate positions and even may not know that intermediates exist. Thus, students are often surprised to learn that some prominent scientists think that there is no necessary conflict between science and religion (e.g., Alexander 2014; Ayala 2007; Baker 2007; Collins 2007; Gould 1999; Miller 2008). Some science faculty at religiously conservative colleges (c.f. Haarsma and Haarsma 2011) and many Christian clergy and Jewish rabbis agree (e.g. Zimmerman 2019).

Smith (2010b, p. 550) suggested: "Teachers will find it helpful to recognize both a range of religious views that students may hold and a range of views of the relationship between science and religion." Presenting students with a multi-position gradient (young-earth creationist, progressive creation, theistic evolutionist, non-theistic evolutionist, and atheistic evolutionist) encourages them to explore what kind of creationist, if any, that they currently might be and, thus, to consider integrating evolution with other views (Nelson 1986, 2000). Alternatively, one might use the groups found empirically by Brem et al. (2003): creationists (strong creationists, human-only creationists, nonspecific creationists), uncertain, and evolutionists (nonspecific evolutionists, interventionist evolutionists, theistic evolutionists, nontheistic evolutionists). Either way, it is important to emphasize the diversity of theological positions and the tradeoffs that lead to some of these choices (Nelson 1986, 2000). Haarsma and Haarsma (2011) discuss ten different theological positions pertinent to evolution and argue that "evolutionary creation" is preferable.

Smith and Scharmann (Smith 2010a, b; Smith and Scharmann 2008) have taught Gould's (1999) view of science and religion as separate, non-overlapping major intellectual realms together with Moore's (1984) view of science as one of several valid ways of knowing. This "has been a productive approach for evolution teaching and learning with our very religious students" (Smith 2010a, p. 531). However, Anderson (2007) argues that even if Gould's view is valid, greater engagement with students' religious ideas is necessary. Even a single highly structured combined lecture and laboratory period can lead to more positive views toward evolution and to more complex views of the nature of science when used for an open and respectful discussion of students' views on evolution and creation and for discussion of what should be taught in science classes (Barnes et al. 2017; Borgerding 2017; Borgerding and Dagistan 2018; Scharmann 1990).

Additional studies also indicate the benefits of acknowledging the different beliefs of students (Ingram and Nelson 2006, 2009; Verhey 2005). The end product of this engagement is an increase in students' ability to reconcile religious views with evolutionary explanations (Southerland and Scharmann 2013; Verhey 2005; Winslow et al. 2011).

Discussion: NOS helps us address misconceptions and decrease resistance to evolution

The three preceding extended instructional examples show how we can use NOS to help students overcome problems in understanding evolution. But why are these problems so difficult to overcome? How further can we use NOS to help us overcome them?

- Overarching problem 1: misconceptions.

Scientific reasoning, our understanding of the nature of science and our understanding both of the processes of evolution and of the overwhelming support for evolution are together so powerful that the rejection of evolution can seem quite puzzling. But misconceptions about evolution are deep and fundamental. Centrally, evolution is "counterintuitive" as it "radically challenges an everyday understanding of the world as stable, purposeful and designed" (Evans et al. 2012, p. 174; see also Rosengren and Evans 2012; Shtulman and Calabi 2012 and other chapters in Rosengren et al. 2012).

A clear understanding of the nature of science is essential to challenging these fundamental misconceptions as well as misconceptions generally. Thanukos and Scotchmoor (2012) emphasized that NOS is often misunderstood or, even, misrepresented. They strongly recommended that learners be introduced to explicit NOS examples and be provided multiple opportunities to reflect on these NOS examples in relation to their study of evolution.

In addition to these fundamental misconceptions, there are many common and often strongly held misconceptions about evolution and NOS (Thanukos and Scotchmoor 2012 and other chapters in Rosengren et al. 2012) as there are about all of science (Duit 2009 provides an annotated bibliography). These include additional basic misunderstandings of the nature of science. One basic misunderstanding is thinking that evolution is a "just a theory" and is thus weak or is just a belief parallel to those of religion (Orfinger 2015), a view that we have shown how to counter in the three major instructional examples developed earlier.

Macroevolution, especially as portrayed in evolutionary trees, poses severe conceptual problems that include some arising from perceptual processing as well as others arising from prior knowledge and confirmation bias (Catley et al. 2012; Matuk and Uttal 2012). The "Measure of Understanding of Macroevolution" provides a more complete list and is a tool for assessing these misconceptions (Nadelson and Southerland 2010). Understanding macroevolution is essential for understanding of the strength of the evidence showing that evolution has occurred (Padian 2010) and "is perhaps the primary stumbling block" for those who have difficulty accepting evolution (Smith 2010b, p. 541). Macroevolution has often been neglected due to an emphasis on microevolutionary processes and the misperception that microevolution is core to understanding the policy implications of evolution (Southerland and Nadelson 2012). Moreover, a solid understanding of macroevolution is core to fostering students' acceptance of evolution (Brem and Sinatra 2012; Chinn and Buckland 2012; Southerland and Nadelson 2012).

Lectures typically have not provided an effective challenge to misconceptions even when they explicitly addressed misconceptions found in the very students being taught (e.g. Arons 1976; Grant 2008, 2009). Even approaches that explicitly address fundamental constraints usually have had limited success in overcoming specific misconceptions (e.g. Catley et al. 2012; Chi et al. 2012; Shtulman and Calabi 2012; Southerland and Nadelson 2012). However, changes have sometimes occurred in a substantial majority of the students when interventions focused on key misconceptions (e.g., Shtulman and Calabi 2012). The relatively small gains overall suggest that interventions need to be more comprehensive (Rosengren and Evans 2012). Carefully structured "learning progressions" illustrate such an approach (Evans et al. 2012), one that would introduce developmentally suitable biological concepts at various grades. Such an incremental approach could help students in "finding a place to stand" in their acceptance of evolution as a powerful tool for explaining biological phenomena (Scharmann 1990). An overview that emphasizes a multiple-constraints explanation is now emerging (Rosengren and Evans 2012) as delineated and partially synthesized in a recent volume (Rosengren et al. 2012). It is evident that multiple aspects of the nature of science will have to be addressed explicitly and effectively to generate widespread change (Furrow and Hsu 2019).

- Overarching problem 2: understanding evolution often is not sufficient for acceptance.

Scientists may assume that students would accept evolution if they just understood its concepts, the strength of the supporting evidence and the relevant NOS. But it is clear from cognitive development that there is no necessary relationship between understanding and acceptance (e.g., Ingram and Nelson 2006). Indeed, increased understanding of evolution usually has not been associated with increased acceptance (citations in Nelson 2012a, b; Smith 2010a). But some recent studies have found a significant relationship for college students, sometimes using broader measures for understanding and acceptance (Ha et al. 2012; Shtulman and Calabi 2012; Weisberg et al. 2018).

Major increases in acceptance are possible using an approach that focuses on NOS, on scientific misconceptions and on non-scientific barriers. Unusually large gains in both understanding and acceptance in pre-service teachers were produced by an approach that explicitly addressed both cognitive barriers (misconceptions of NOS and of micro- and macro-evolution) and non-scientific (political, religious and emotional) barriers (Southerland and Nadelson 2012).

Cognitive complexity and a rich understanding of NOS are made especially important for evolution by students' views of consequences. Students who accepted evolution and students who rejected it both usually viewed the consequences of accepting it negatively:"*increased selfishness and racism, decreased spirituality, and a decreased sense of purpose and self-determination*" and, worse, both more exposure to evolutionary ideas and a greater knowledge of the principles and mechanisms of evolution were associated with *more negative* views of its consequences (Brem et al. 2003, p. 181).

A study of the effects of students' initial scientific and religious conceptions on subsequently understanding and accepting evolution found that "conceptual change has significant affective components" as "evaluation is often based on extralogical criteria" such that "goals, emotions and motivations play a significant role" (Demastes-Southerland et al. 1995, pp. 637–638, 661). Thus, even when students clearly understand evolution, some "may choose not to believe" evolution "because they use different standards of evidence or refuse to abandon alternative core beliefs" (Ferrari and Chi 1998, p. 1250). These negative views make it especially important in teaching evolution to explicitly address benefits (as in Darwinian medicine) and the potential negative consequences. Wilson (2005) suggested that we should begin in teaching evolution by addressing the perceived negative consequences.

Students must learn critical thinking and understand a sophisticated model of the nature and limits of science if we want to enable them to deal with controversies involving science and its applications (Nelson 1986, 2007, 2012a, b; Sinatra et al. 2003). We have found that a deep understanding of the nature of science helps students understand and accept the scientific validity of evolution and, conversely, that evolution provides an especially effective context for helping students and teachers develop a deep understanding of the nature of science.

Sinatra et al. (2003) suggested teaching the nature and limits of scientific knowledge to foster acceptance of evolution, an approach we have developed in detail above and earlier (Nelson 1986, 2000, 2007; Nelson et al. 1998; Scharmann and Harris 1992; Smith and Scharmann 1999; Scharmann et al. 2005). When this is done in ways that allow a consideration of the relation between science and religion and of ways of combining science and personal beliefs, then there can be marked increases in the probability of students changing to be more accepting of the validity of evolution (Bertka et al. 2019; Ingram and Nelson 2006, 2009; Lombrozo et al. 2008; Manwaring et al. 2015; Rutledge and Warden 2000; Smith 2010a; Southerland and Nadelson 2012; Southerland and Scharmann 2013; Southerland and Sinatra 2003; Verhey 2005, 2006). As noted above, high school biology teachers who understood the nature of science and its relations to religious claims better were more likely to teach evolution extensively and effectively (Nelson et al. 1998; Scharmann and Harris 1992). The three extended examples we provided above explain how we approached this.

Paradoxically, although interactive comparisons of religious views with evolution are more effective than approaches that focus only on the science in getting students to accept evolution and teachers to teach evolution, many college faculty and high school teachers have been reluctant to address religion. The reasons include viewing the teaching of creationism as inappropriate in a science class, feeling pressure to cover scientific content, feeling a lack of preparation for dealing with religious topics, and being reluctant to confront students' beliefs or to be challenged in class (Alters 2005, 2010; Blackwell et al. 2003; Griffith and Brem 2004). But, again, ignoring religion leaves students unconvinced and teachers less likely to forthrightly present evolution. Further, science-only approaches have not fostered any substantial change in its acceptance by the general public over the last few decades (Newport 2009) despite a considerable increase in the proportion of the population that is college educated.

Conclusions

To really understand evolution, students must also have a deep understanding of the nature of science. Further, evolution provides an especially effective framework for fostering a deep understanding of NOS. Similarly, to foster the effective teaching of evolution we must provide secondary biology teachers with: (a) a deep understanding of NOS, (b) ways to help students deal with the implications they see from evolution, and c) an understanding of appropriate pedagogy. It is also essential in preparing secondary biology teachers that the teachers work through examples of fully developed lessons and unit plans that incorporate emphases on NOS, evolutionary processes, and utilize pedagogies that effectively foster science learning (Flammer 2016).

Traditional teaching has not worked nearly as well as is often assumed either for the nature of science or for evolution. Other pedagogies (e.g., cooperative learning, problem-based instruction, peer discussions) that work well for less contested ideas are helpful for evolution, but not sufficient (Nelson 2009). Acceptance of some combination of religion with some or all of the core ideas of evolution is common among scientists, theologians and clergy as well as among students and the general public (Winslow et al. 2011). Research suggests that to foster a serious consideration of evolution we should help students compare evolution with creationist ideas. However, it is essential to note that local political and social contexts may make this ill advised for many pre-college settings (Scharmann 2005). Importantly, we do *not* support teaching "two (equivalent) models" or any other approach that does not provide students with appropriate criteria for comparing ideas when suggested as scientific.

Overall, then, we need to foster a deep understanding of the nature and limits of science; open-minded, non-absolutist cognitive dispositions; critical thinking and advanced cognitive development; and respect for multiple perspectives (Nelson 2008, 2012a, b). We also need to be able to address the beliefs that students bring into the classroom through instructional practices that foster ways to think deeply about complex problems such that students begin to consider a need to question their own beliefs and assumptions. This does *not* mean advocacy of our own views. Instead we need to help students understand both the overwhelming scientific strength of evolution as well as why a wide array of alternatives exists for combining science and religion in personal perspectives.

Abbreviations

BSCS: biological sciences curriculum study; ENSI: evolution and nature of science institutes; ID: intelligent design; NOS: nature of science; NOSPET: nature of science and premises of evolutionary theory; NSF: National Science Foundation; SENSI: secondary evolution and nature of science institutes.

Authors' contributions

CEN and LCS conceived the article. CEN, LCS, JB, and LIF wrote the original manuscript. CEN and LCS edited multiple drafts resulting in the final submission of the article (LCS served as the corresponding author). All authors read and approved the final manuscript.

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Acknowledgements

Lawrence (Larry) Flammer passed away in December 2017 after making significant contributions to an earlier manuscript draft. Larry taught college preparatory biology to junior and senior high school students for 38 years. His love for teaching, respect for students, and admiration for the wonder/power of biological processes was surpassed only by the deep love he expressed for his family. The instructional insights described in the initial case were derived in large part from being tried and refined in Larry's classroom. His service in retirement to the ENSI project as its web master permitted thousands of biology teachers access to lesson plans and instructional resources designed specifically to enhance instructional success in teaching evolution and the nature of science.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

Received: 24 September 2018 Accepted: 7 February 2019
Published online: 13 February 2019

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