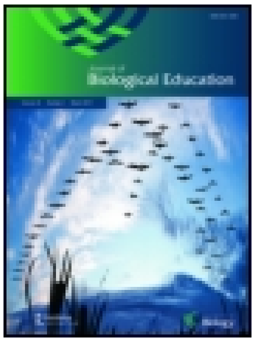

Routledge
Taylor & Francis Group

Journal of Biological Education

ISSN: 0021-9266 (Print) 2157-6009 (Online) Journal homepage: http://www.tandfonline.com/loi/rjbe20

The effect of teaching the nature of science on students' acceptance and understanding of evolution: myth or reality?

Hernán L. Cofré, David P. Santibáñez, Juan P. Jiménez, Angel Spotorno, Francisca Carmona, Kasandra Navarrete & Claudia A. Vergara

To cite this article: Hernán L. Cofré, David P. Santibáñez, Juan P. Jiménez, Angel Spotorno, Francisca Carmona, Kasandra Navarrete & Claudia A. Vergara (2017): The effect of teaching the nature of science on students' acceptance and understanding of evolution: myth or reality?, Journal of Biological Education

To link to this article: http://dx.doi.org/10.1080/00219266.2017.1326968

Published online: 15 May 2017.

JOURNAL OF BIOLOGICAL EDUCATION, 2017
https://doi.org/10.1080/00219266.2017.1326968

Routledge
Taylor & Francis Group

Check for updates

The effect of teaching the nature of science on students' acceptance and understanding of evolution: myth or reality?

Hernán L. Cofré[a], David P. Santibáñez[b,c], Juan P. Jiménez[c], Angel Spotorno[d], Francisca Carmona[a], Kasandra Navarrete[a] and Claudia A. Vergara[e]

[a]Instituto de Biología, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile; [b]Facultad de Educación, Universidad Católica Silva Henríquez, Santiago, Chile.; [c]Mathematics and Science Education Department, Illinois Institute of Technology, Chicago, IL, USA; [d]Facultad de Medicina Norte, Universidad de Chile, Santiago, Chile; [e]Facultad de Filosofía y Humanidades, Universidad Alberto Hurtado, Santiago, Chile

ABSTRACT

The results of studies of the nature of science (NOS) as a factor that enhances students' understanding of evolution have been inconclusive. Therefore, the main purpose of this study was to test the role of NOS instruction in enhancing students' learning about evolution. We used a quasi-experimental design with pre- and post-tests to investigate the impact of teaching evolution with and without NOS in two classes with 15–16-year-old students, who were randomly assigned to these two classes. To measure their understanding of NOS and their acceptance and understanding of evolution, we used three different instruments that have been shown to generate reliable and valid inferences in comparable populations. The main results of this study were that, in the class in which the teaching of evolution included NOS instruction, the students' understanding of NOS and their acceptance of evolution significantly improved. However, irrespective of the use of NOS instruction, both classes increased their understanding of evolution. These results support the claim that NOS instruction may influence students' acceptance of evolution but not their understanding of evolution and natural selection.

KEYWORDS

Nature of science; acceptance of evolution; understanding of evolution; natural selection

Introduction

Evolution is widely regarded as a unifying concept in biology (e.g. Dobzhansky 1973), and evidence in fields such as palaeontology, evolutionary ecology and evolutionary biology has supported the theory of evolution (e.g. Futuyma 2009; Coyne 2010). Nevertheless, the incomprehension and denial of this theory among biology teachers, undergraduate students and high school students have been identified as some of the most important issues in biology education (e.g. Alter and Nelson 2002; Kampourakis and Zogza 2007; Banet and Ayuso 2003; Pazza, Penteado, and Kavalco 2010; Kim and Nehm 2010; Nunez, Pringle, and Showalter 2012; Taşkın 2013; Mpeta, de Villiers, and Fraser 2015). In addition, teaching and learning evolution is one of the main topics in current research in science education (e.g. Bayer and Luberda 2016; Donnelly et al. 2016; Emmons, Smith, and Kelemen 2016; Fowler and Zeidler 2016).

According to the latest reviews on the teaching and learning of evolution, some evidence connects teachers' and students' understandings of the nature of science (NOS) with their understanding and

CONTACT Hernán L. Cofré hernan.cofre@pucv.cl

acceptance of evolution (Sickel and Friedrichsen 2013; Glaze and Goldston 2015; Mpeta, de Villiers, and Fraser 2015). Because the NOS helps students learn how scientific knowledge is generated and tested and how scientists do what they do (Lederman and Lederman 2014), understanding NOS has been suggested to provide a framework within which students can incorporate new content knowledge (Lederman 2007).

However, little empirical evidence has clearly linked NOS with evolution.

Regarding the issue of teaching and learning evolution, several correlational studies have established associations between understanding NOS and understanding evolution, ranging from small (Nehm, Kim, and Sheppard 2009) to large positive correlations (Rutledge and Warden 2000). Some studies have found a positive relationship among college students (Nehm and Schonfeld 2007; Kim and Nehm 2011), pre-service teachers (Akyol et al. 2012; Ha, Haury, and Nehm 2012), and in-service teachers (Rutledge and Warden 2000), whereas other studies have not found such a relationship between college students and teachers (e.g. Rutledge and Sadler 2011; Cofré et al. 2013, 2016).

Furthermore, some studies have found a positive correlation between students' and teachers' conceptions of NOS and their acceptance of evolution (Rutledge and Mitchell 2002; Lombrozo, Thanukos, and Weisberg 2008; Akyol et al. 2012; Carter and Wiles 2014; Nadelson and Hardy 2015). To explain this relationship, Rutledge and Mitchell (2002) proposed that teachers with naïve views on NOS were incapable of distinguishing between the scientific validity of evolution and religious beliefs. In another study, Akyol et al. (2012) found a significant positive relationship between pre-service science teachers' views of NOS and their acceptance of the theory of evolution. In that study, which included 415 preservice science teachers, participants with more sophisticated views of NOS tended to accept evolution more than other participants. In a more qualitative approach, Dagher and Boujaoude (2005) showed that college students who were uncertain about the theory of evolution held one or more of the following misconceptions about the status of evolution as a scientific theory: the theory of evolution is not supported by concrete evidence; evolution has not yet been proven like cell theory; the theory of evolution lacks experimentation; research about evolution has skipped one or more of the steps of the scientific method; and/or scientists are unable to predict the course of evolution. Nevertheless, other studies have failed to demonstrate a positive relationship between understanding NOS and accepting evolution (e.g. Sinatra et al. 2003). Therefore, the relationship between NOS and the acceptance and understanding of evolution has been very difficult to disentangle.

These results have led some authors to propose a relationship model that suggests that views on NOS are directly related to both understanding and accepting evolution (Akyol et al. 2012). However, other authors have claimed that students with low levels of understanding of evolution may accept it as valid or that those who do not accept it as a valid scientific theory may have a good understanding of it (Sinatra et al. 2003).

Despite this lack of conclusive results, few studies focus on improving students' knowledge and acceptance of evolutionary theory (e.g. Kampourakis and Zogza 2007; Banet and Ayuso 2003; Álvarez and Ruiz 2015; Gonzalez-Galli and Meinardi 2015; Bayer and Luberda 2016; Emmons, Smith, and Kelemen 2016), and, to the best of our knowledge, no studies use a quasi-experimental design to relate the understanding of NOS to the understanding and acceptance of evolution (Glaze and Goldston 2015). Therefore, investigations are critically needed to determine the impact of strategies that teach evolution by incorporating NOS on students' understanding and acceptance of evolution.

Context of the study

The Chilean educational system is a difficult environment in which to promote innovation in science education (Cofré et al. 2015). In secondary classrooms, the average class size is 30 students; the average number of teaching hours per year in public secondary schools is 860; and the salaries of science teachers with at least 10 years of experience are no higher than USD 15,000 per year (Cofré et al. 2015). The government prescribes the curricula for both public and private schools. For natural sciences, the scientific literacy objective, including some aspects of NOS, was set at the end of the twentieth century (Cofré et al. 2015), but many biology teachers hold uninformed views about NOS and evolution (Cofré et al. 2014, 2016).

Biological evolution is a cornerstone of the national secondary school curriculum as well as the documents that set standards for biology teachers' education. In high school, students must learn about genetic variation, inheritance, natural selection and human evolution (MINEDUC 2009). Due to this coverage over the past two decades and the absence of any explicit treatment of topics such as intelligent design, some authors have proposed a positive scenario in terms of the understanding of evolutionary theory among the Chilean population (Medel 2008). Nevertheless, the results of the few studies of students' and biology teachers' understanding and acceptance of evolution do not show very strong correlations. In a study that included three different universities and a sample of 50 in-service science teachers, nearly 70% of teachers and undergraduate students recognised the theory of evolution as established scientific knowledge (Cofré et al. 2016). Furthermore, a recent study conducted in a traditional university showed that the acceptance of evolution increased among those with advanced degrees and that this correlation was stronger for participants who studied biology and physics compared with those who studied chemistry (Marín and D'Elía 2016). In addition, the most common response from students and teachers regarding the explanation of evolutionary changes revealed a misconception about need-driven changes for survival purposes (Cofré et al. 2013, 2016), i.e. that internal (the organism itself) or external (environment) factors changed to satisfy new needs (Kampourakis and Zogza 2007). Such explanations are teleological in the sense that changes occur to trigger the organisms' local adaptations.

Purpose of study and research questions

In this context, this study was guided by the following questions: (1) How well do Grade 11 students understand NOS before the intervention? (2) To what degree do Grade 11 students understand and accept the theory of evolution before the intervention? and (3) To what extent does teaching evolution with NOS improve these students' understanding and acceptance of the theory of evolution compared with that of the control group (teaching evolution without NOS)?

Methods

Study design and participants

We used a quasi-experimental design to investigate the impact of NOS and evolution instruction on students' understanding and acceptance of the theory of evolution with a pre-and post-test assessment (Fischer, Boone, and Neumann 2014). This study included a group of secondary students. The participants were 46 students in Grade 11 who were randomly assigned to two classes. Because some students lacked all the information about the test at the end of the study, 19 students in the class with NOS instruction and 20 students in the class without NOS instruction were ultimately studied.

Intervention

The study included two classes. One class added NOS instruction in an explicit and reflective way (Lederman 2007), and in the other class NOS was not taught at all. In the experimental class, two lessons (90 min each) were conducted in which students explicitly discussed and reflected on different aspects of NOS. The lessons included three decontextualised activities and one activity contextualised in an evolutionary topic (Figure 1). The decontextualised activities focused the students' attention on a particular NOS aspect. This approach isolated and emphasised a fundamental NOS aspect in familiar and concrete ways that were not complicated by scientific content (Clough 2006). The decontextualised activities were 'the tube', 'the cube' and 'tricky tracks' (Lederman and Abd-El-Khalick 1998). 'The tube' is a black box activity in which students are shown a tube and its behaviours; they are then

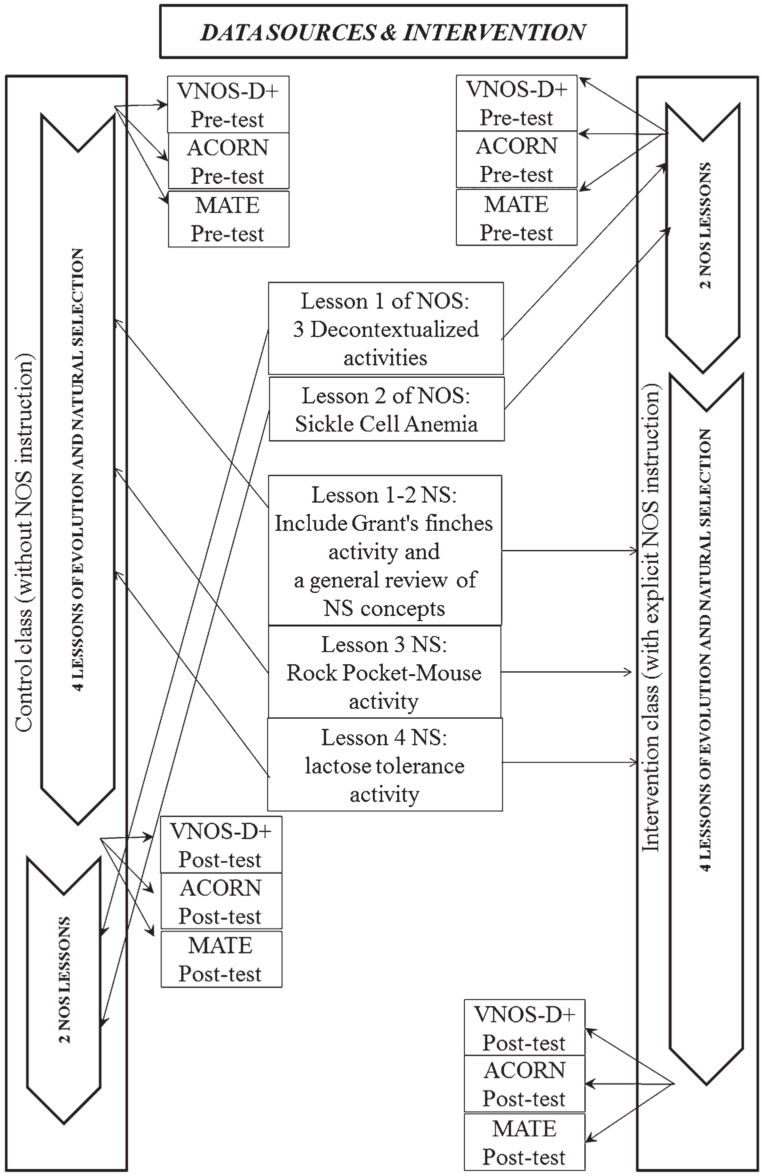

Figure 1. Timeline, intervention and data collection undertaken in the study.
Notes: NS = Natural Selection; NOS = Nature of Science.

asked to infer the structure inside the tube and to design and construct physical models that behave in the same manner (Lederman and Abd-El-Khalick 1998; for more detail, see Cofré et al. 2014). The contextualised activity involved a case of human evolution: 'The discovery of resistance to malaria of sickle-cell heterozygotes' (Cofré et al. 2016; see Rudge and Howe 2009 for more extensive planning with this example). After that, four 90-min lessons were applied in which natural selection and NOS were discussed. Among the different activities included in the NOS and evolution lessons were discussions of five aspects: the difference between observation and inference; the myth of the scientific method; the differences between hypothesis, theory and law; the contributions of creativity and subjectivity in science; and the empirical basis for the generation of knowledge. All these aspects were included to conflict with students' misconceptions, such as 'evolution is just a theory', 'evolution is not supported by empirical evidence', 'the theory of evolution lacks experimentation' or 'the theory of evolution is only what Darwin proposed' (e.g. Dagher and Boujaoude 2005). By contrast, the lessons about evolution focused on students learning about the mechanism of natural selection. Specifically, we highlighted that the mechanism is based on three essential components: variation, differential fitness (reproduction and survival) and inheritance (Futuyma 2009). Our aim was to destabilise students' finalist thinking (Gonzalez-Galli and Meinardi 2015). This part of the intervention consisted of three activities: one devoted to the 40-year project conducted by researchers Peter and Rosemary Grant on the beaks of Darwin's finches (e.g. Grant 1999); another based on the work of Michael Nachman regarding the fur adaptation of the rock pocket mouse (e.g. Nachman, Hoekstra, and D'Agostino 2003); and a final lesson about lactose tolerance as an example of natural selection in humans (e.g. Ingram et al. 2009). All three activities included a working guide and the viewing and analysis of a video by the Howard Hughes Medical Institute (https://www.youtube.com/user/biointeractive). The guide was used in groups of three, and its main objective was to help students understand and be able to apply the mechanism of natural selection (Álvarez and Ruiz 2015). In each class, questions were also included that asked students to reflect on different aspects of the nature of evolutionary knowledge. The control class only included the four lessons about natural selection. These lessons were student centred and included collaborative work, analyses of video materials and a conceptual change strategy for the destabilisation of misconceptions about natural selection. In this class, the two lessons on NOS were conducted after the study, and the data collection was completed.

Instruments and data collection

Before the intervention in each class, students answered three questionnaires that had been subjected to reliability and validity evaluations and that had been widely used in the international literature. The teachers responsible for the intervention answered any questions that students had (Figure 1).

The students' views of NOS were assessed using the Views of NOS form D+(VNOS-D+) instrument (Lederman et al. 2002; Cofré et al. 2014, 2016). Although NOS is a complex concept that can include aspects beyond those assessed in the VNOS-D+ questionnaire, the aspects therein have been studied for more than 60 years in science education, and most instruments developed to assess knowledge about NOS include them (Abd-El-Khalick 2014). In addition, this approach has been used previously in studies of the relationship between knowledge of evolution and understanding of the NOS (e.g. Kim and Nehm 2010). Therefore, the VNOS-D+ questionnaire was used to assess students' understanding of NOS before and after the intervention (Lederman and Khishfe 2002).

We used the Assessment of Contextual Reasoning about Natural Selection (ACORNS), one of the most commonly used questionnaires used in the current literature, to assess students' understanding of the natural selection mechanism (Nehm et al. 2012) because a detailed study of this instrument's validity and reliability had been reported by Nehm et al. (2012). According to these authors, good evidence supports convergent validity because of the high correlation between the results of ACORNS and the responses of the same participants in clinical interviews and other quantitative instruments, such as CINS (The Conceptual Inventory of Natural Selection, Anderson, Fisher, and Norman 2002). They also showed measures of high reliability (Cronbach's alpha between 0.67 and 0.77). The format of ACORNS items is as follows: 'How would biologists explain how a species of X [with or without a trait] evolved from an ancestral Y species [without or with]?' We used four ACORNS items differing in surface features (e.g. animal vs. plant, trait gain vs. trait loss) to assess students' knowledge in the pre- and post-tests.

To assess the students' acceptance of evolution, we used the Measure of Acceptance of the Theory of Evolution (MATE) instrument, developed by Rutledge and Warden (2000). This questionnaire consists of 20 items covering six scales, including human evolution and the scientific validity of evolutionary theory. The MATE items are answered on a five-point Likert scale (strongly agree to strongly disagree). We used the MATE because its validity and reliability had been established (e.g. Rutledge and Warden 2000; Nadelson and Sinatra 2010).

Because this study was conducted in a Spanish-speaking country, the three instruments had been translated and previously validated in this language (Cofré et al. 2015, 2016).

Data analysis

To analyse the effect of the intervention, only students who answered the questionnaires at the beginning and the end of the study and attended most of the lessons (four of six) were considered, which decreased the final number of students in the study.

The grading scheme for analysing the NOS instrument was the same as that widely used in the literature (e.g. McDonald 2010; Cofré et al.2014, 2016). If a response clearly showed that the student's opinion reflected the recommended opinion, the response was coded as 'informed' (a value of 2). If the answer was aligned with the recommended position but was not fully developed or expressed or it was simply a reiteration of the definition provided, it was coded as 'mixed' (a value of 1). If the answer showed that the student's opinion was not aligned with the recommended position, the answer was coded as 'naïve' (a value of 0). For each student, two authors independently coded each response according to these criteria (DS and JPJ). The authors met and discussed each score to achieve consensus. In total, 90% of the baseline scores were identical, and all disagreements were resolved in conversation; in addition, most codes were identical in the coding of the final questionnaires (95%). To generate a quantitative analysis to supplement the qualitative description of each student's profile, an 'understanding of NOS' variable was created using the sum of the values obtained for each aspect for each student. As 7 aspects were studied and the values for understanding NOS ranged between 0 and 2, each student's quantitative profile could fluctuate between 0 and 14 points.

A modification of the rubrics of Nehm et al. was used to score the ACORNS responses (Cofré et al. 2016). From the open questionnaire responses, ACORNS could determine both the correct items in the answers and the presence of misconceptions about the mechanism of evolution by natural selection. When evaluating student responses, a response was considered 'Darwinian complete' when it presented the main aspects of natural selection: environmental change (selective pressure), variability in the population, the reasons for variability (mutation), the inheritance of phenotypic variation and differential reproduction and survival. If the answer was missing any of these components, the response was considered 'Darwinian incomplete'. The rubrics included detailed scoring information for 10 key concepts (accurate ideas) and six alternative conceptions or naïve ideas. Key concept (KC) scores for each item could range from 0 to 10, and alternative conception scores could range from 0 to 6. Thus, the maximum KC score across all four items was 40, and the maximum alternative conception score was 24. Participants' responses that incorporated aspects from more than one category were classified as mixed responses. Three authors analysed the responses, and 92% consistency was obtained. Discrepancies were discussed, and a consensus was reached among the three researchers (FC, KN and HC). To perform a descriptive and qualitative analysis of students' understanding of the mechanism of natural selection prior to the intervention, the kind of response given by each student was registered and classified as correct Darwinian responses (complete and incomplete) or preconceptions. Participants' responses that incorporated aspects of more than one category were classified as mixed. The misconceptions were teleological (evolution through need via purposeful change), Lamarckian (use and disuse theory and the inheritance of acquired characteristics), Amechanistic (evolutionary change explained because of different evidence [fossil, genetic, or morphological], not by a mechanism) and chimerical (new species originate from the mixture of two existing species).

To perform a quantitative analysis of change in students' understanding of the mechanism of natural selection, all the questions were counted (4 in total), including the number of correct concepts and the number of preconceptions included in each answer. Along with these two variables, a final variable, 'knowledge', was created by adding each of the variables above. This variable requires that the presence of preconceptions take a negative value. Thus, if a response included two correct concepts and 3 conceptual errors, the value of the variables would be as follows: correct knowledge = 2; the presence of preconceptions = 3; overall knowledge = −1 (2–3).

As in previously published studies, MATE scores were transformed into a 100-point scale, ranging from 20 points (indicating total rejection) to 100 points (indicating complete acceptance).

The analysis of the three questionnaires was performed in a graphical form and with statistics. To determine if a significant difference existed in each variable's score before and after the intervention in both classes (with and without NOS instruction), we used the student's *t*-test for related samples (Field 2011). We also calculated the effect size of the intervention for each variable. All statistical tests were performed in SPSS, version 19.

Results

Students' understanding of NOS before and after the intervention

The first important result is that NOS aspects that were not included in the lesson plans did not produce an increase in either class. Table 1 shows that tentative and sociocultural aspects of NOS, which were not included in any lessons, showed the same scores before and after the intervention. However, in the class in which NOS was taught explicitly and reflectively, an increase was found in three of the five NOS aspects included in the lesson plan (creativity, subjectivity and the difference between observation and inference), but theory and law and the empirical aspects did not improve students' scores (Table 1).

According to the statistical analysis performed, we found that, on average, students learned significantly more NOS in the treatment class ($t[14] = -2.7$; $p < 0.05$; $r = 0.64$) than did students in the control class ($t[16] = -0.9$; $p = 0.39$; $r = 0.22$). Figure 2 shows the distribution values of NOS scores for the control class (pre-test mean = 6.35; post-test mean = 6.75) and for the treatment class (pre-test mean = 5.60; post-test mean = 7.13).

Students' understanding of evolution with and without NOS instruction

Before the intervention, most students explained evolutionary change via purposeful need or teleology or simply did not know how to explain it. Interestingly, genuinely Lamarckian explanations (use and disuse) were not represented (Figure 3).

In terms of understanding evolution, the students' knowledge of evolutionary theory before the intervention was significantly lower than their understanding after lessons in the class without NOS instruction (pre-test mean = −1.1; post-test mean = 4.0; $t[15] = -5.8$; $p < 0.001$; $r = 0.83$) and in the treatment class (pre-test mean = 0.13; post-test mean = 3.06; $t[14] = -2.2$, $p < 0.05$; $r = 0.51$), but the effect size in this latter group was lower. Thus, after the intervention, many students in both classes were able to explain evolutionary change; they provided not only more correct concepts related to the mechanism of natural selection, but also fewer conceptual errors in their explanations (Figure 4).

Table 1. Percentage of students in each of the categories of understanding for each NOS aspect.

View of NOS	Tentative		Creative		Inferential		Subjective		Theory & law		Socio & cultural		Empirical	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
With NOS														
Naive	0	6	18	0	67	24	56	13	31	25	41	63	0	0
Mix	100	94	65	63	27	59	44	47	56	56	53	31	29	29
Informed	0	0	18	38	7	18	0	40	13	19	6	6	71	71
Without NOS														
Naive	6	12	11	0	83	32	20	17	28	29	53	53	0	6
Mix	89	88	56	67	6	63	50	67	56	59	29	24	11	39
Informed	6	0	33	33	11	5	30	17	17	12	18	24	89	56

Note: Aspect of difference between observation and inference, creativity and subjectivity are the aspect that most improve.

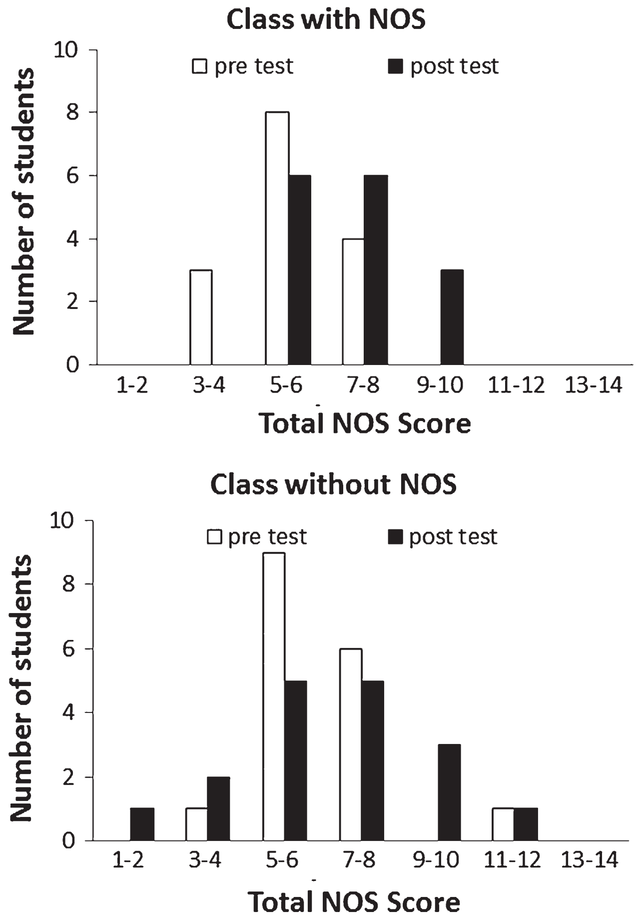

Figure 2. Number of students with different scores in total understanding of nature of science before and after the intervention (white and black bars, respectively) in classes with and without NOS instruction.

Students' acceptance of evolution with and without NOS instruction

Before the intervention, both classes showed a moderate level of acceptance of the theory of evolution, reaching a mean score near 75 (from a maximum of 100%) (Figure 5). After the lessons, students in the experimental class showed, on average, greater acceptance (post-test mean = 89.21) than they did before (pre-test mean = 84.26) the intervention ($t[18] = -3.3$ $p < 0.01$; $r = 0.61$). However, in the control class, students' acceptance before (pre-test mean = 86.00) the intervention was not different from their acceptance after (post-test mean = 87.45) the lessons ($t[19] = -0.8$, $p = 0.43$; $r = 0.18$).

Discussion and conclusions

Students' understanding of NOS before and after the intervention

According to the assessment conducted before the lessons, students showed a low understanding of most aspects of NOS, especially the difference between theory and law and the contributions of observations and inferences to developing scientific knowledge. These results are consistent with the current literature (e.g. Lederman 2007). Students who were not explicitly taught NOS failed to learn about these aspects of NOS, which is also consistent with the current literature (e.g. Peters 2012), even though evolution has been described as a favourable topic in which to incorporate NOS (Kampourakis

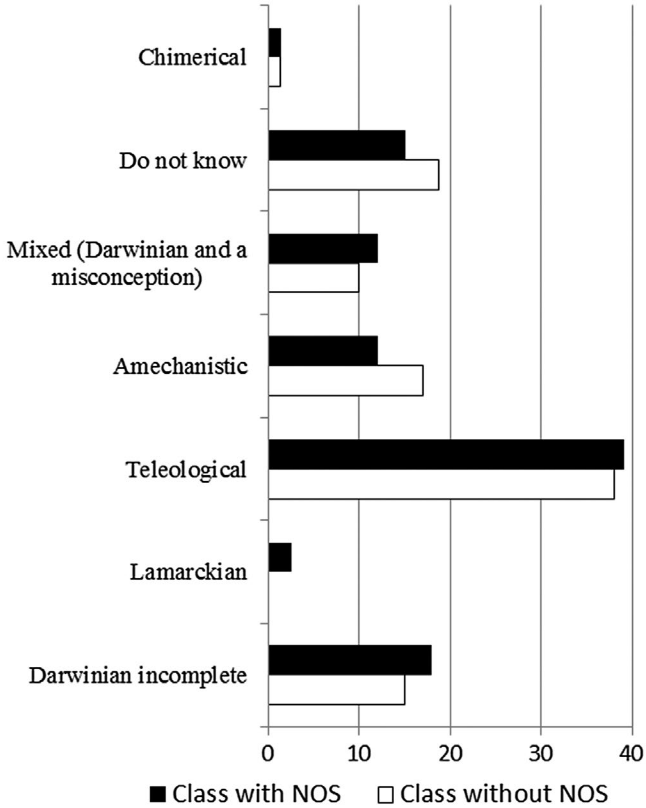

Figure 3. Frequency (%) of the different types of responses that students provide to explain the evolutionary change of one actual species from an ancestral species at the beginning of the intervention.
Note: White and black bars represent the classes with and without nature of science instruction, respectively.

and McComas 2010). Although this intervention was very similar to others described in the literature for high school students (e.g. Khishfe and Lederman 2007; Kim and Irving 2009; Peters 2012), our intervention was not as effective in improving students' understanding of NOS (e.g. Cofré et al. 2014, 2016). This relative lack of effectiveness can be partially explained because understandings of the difference between theory and law and the tentativeness of scientific knowledge, neither of which increased in the treatment class, have been described as the most difficult aspects to improve (Mesci and Schwartz 2017). In addition, most NOS interventions are longer (4–6 lessons) than our intervention (e.g. Khishfe and Lederman 2007; Kim and Irving 2009; Peters 2012).

Students' understanding and acceptance of evolution

At the beginning of the intervention, we found that most students did not understand the theory of evolution and that their ability to explain adaptation through natural selection was negligible, which coincides with the findings described in other studies (e.g. Kampourakis and Zogza 2007; Banet and Ayuso 2003; Gonzalez-Galli and Meinardi 2015). However, by learning about the concepts of natural selection through different activities emphasising conceptual change and evidence of evolutionary phenomena, students' understanding of the mechanism of natural selection significantly improved. These results coincide with those described in the literature, which states that non-traditional, student-centred instruction can improve knowledge about evolutionary theory (Glaze and Goldston 2015). For example, Bayer and Luberda (2016) recently showed that an inquiry-based palaeoanthropology lab can improve knowledge about human evolution among high school students.

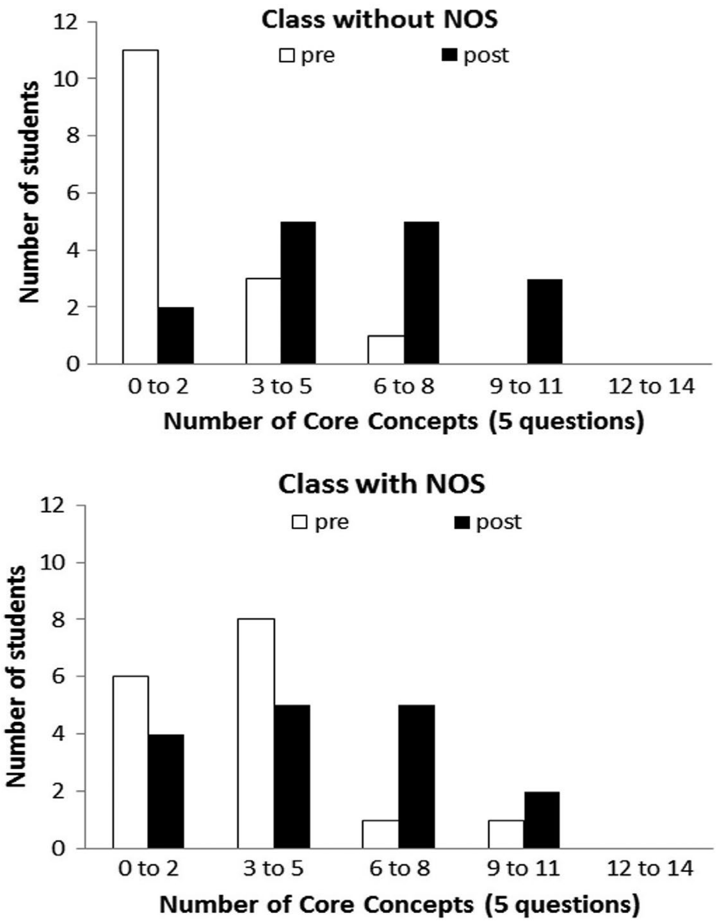

Figure 4. Number of students in different categories regarding knowledge of evolution.
Notes: The categories represent the number of core concepts (correct knowledge) that included all five responses. The theoretical maximum of core concepts was 20 (four for each question).

By contrast, before the intervention, students' degrees of acceptance of the theory of evolution were quite high – similar to results described in the literature for students in European countries. This result does not coincide with the current literature because, in most of the countries where the data suggest lower levels of tension between religion and evolution (such as Chile), significant relationships have been reported between acceptance of evolution and the understanding of evolution (Akyol et al. 2012; Ha, Haury, and Nehm 2012; Kim and Nehm 2011). Because the design of our study (quasi-experimental) differs from those of most of the previous studies of this relationship (correlational), we argue that gaining an understanding of natural selection was not sufficient to improve the acceptance of evolutionary theory. This result can be explained because misconceptions related to acceptance (e.g. no scientific evidence supports evolution) and misconceptions about understanding the mechanism of natural selection (e.g. evolution occurs by necessity) are different issues, and they must be addressed independently and explicitly.

Students' understanding of NOS and its relationship with their understanding and acceptance of evolution

Before our study, research findings were inconsistent with regard to whether the understanding of NOS and the acceptance and understanding of evolution were significantly related, with support both for

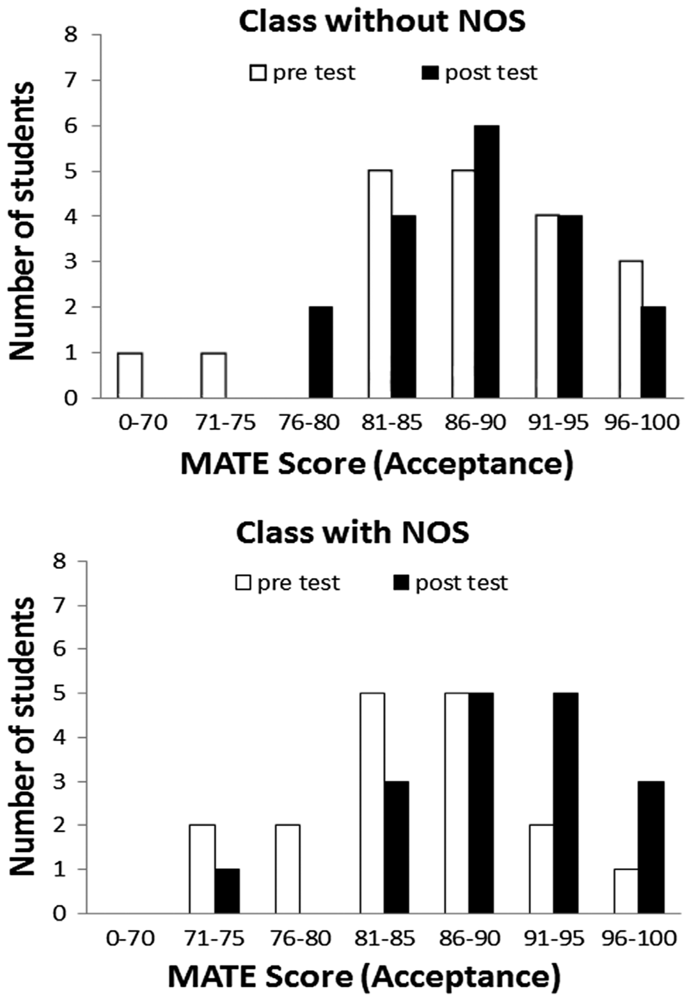

Figure 5. Number of students per category of acceptance generated by the MATE questionnaire before (white bars) and after (black bars) the intervention for each class (with and without NOS instruction).
Note: One hundred per cent indicates total agreement (acceptance) with the 20 propositions included in the instrument

(Rutledge and Warden 2000) and against various combinations of these variables. The designs used in these studies to test their hypotheses may explain these inconsistent results (e.g. Nehm and Schonfeld 2007; Rutledge and Mitchell 2002).

According to the recent revision of Glaze and Goldston (2015), one approach that improves students' understanding and acceptance of evolution is the use of inquiry-based instruction, in which the discussion of some aspects of NOS can be included (Farber 2003; Robbins and Roy 2007; Pramling 2009; Bayer and Luberda 2016). However, from the current literature, we also know that few studies show a significant relationship between NOS and the acceptance of the theory of evolution (e.g. Nehm and Schonfeld 2007; Akyol et al. 2012; Nadelson and Hardy 2015). For example, the recent study by Nadelson and Hardy (2015), conducted with 59 undergraduate students, demonstrated a positive and significant relationship between the acceptance of evolutionary theory and confidence in science and scientists. We have found the following causal relationship: students who were able to reflect on NOS in a context in which evolution was taught showed increased acceptance of this biological knowledge, while students without this opportunity maintained their previous levels of acceptance. This result confirms the potential importance of understanding NOS to the acceptance of evolution as valid scientific knowledge. Because the students in this study did not improve their understanding of theory and law very much, understanding the difference between inference and observation, which improved significantly between pre- and post-tests, is probably another important aspect with regard to the acceptance of evolutionary theory. Furthermore, our results are consistent with the model proposed by Bayer and Luberda (2016), who found that teachers associated students' acceptance of human evolution with the quality of evidence (NOS) furnished by the palaeoanthropology lab.

Conclusions, recommendations and limitations

Despite some limitations in the study, such as the difference in the number of lessons delivered for each class between the pre- and post-tests, our results support the claim that NOS can influence students' acceptance but not their understanding of the mechanism of natural selection. We presented empirical evidence from a quasi-experimental study of how an instructional strategy that includes NOS (with decontextualised and contextualised activities) when teaching evolution is an efficient way of improving students' understanding of NOS and acceptance of evolution because students understand the quality of the evidence supporting the theory. However, we did not find any evidence that NOS instruction performed better than a conceptual change in the instructional sequence to teach evolution without reflecting on NOS. These results highlight that a positive correlation pattern between understanding NOS and understanding natural selection must be interpreted cautiously (e.g. Lombrozo, Thanukos, and Weisberg 2008). Future research should increase the number of classes in which we compare evolution instruction with and without NOS (one limitation of this study), and more sophisticated analyses can be performed to assess how each student in the class changes his/her views about NOS and evolution after different types of instruction, for example, using a more qualitative research approach (Dagher and Boujaoude 2005).

Funding

This work was supported by the Chilean National Fund for Scientific and Technologic Development (FONDECYT) [grant number 1131029].

References

Abd-El-Khalick, F. 2014. "The Evolving Landscape Related to Assessment of Nature of Science." In *Handbook of Research on Science Education*. Vol. II, edited by N. Lederman and S. Abell, 621–650. New York, NY: Routledge.

Akyol, G., C. Tekkaya, S. Sungur, and A. Traynor. 2012. "Modeling the Interrelationships Among Pre-service Science Teachers' Understanding and Acceptance of Evolution, Their Views on Nature of Science and Self-efficacy Beliefs Regarding Teaching Evolution." *Journal of Science Teacher Education* 23 (8): 937–957.

Alter, B. J., and G. E. Nelson. 2002. "Perspective: Teaching Evolution in Higher Education." *Evolution* 56: 1891–1901.

Álvarez, E., and R. Ruiz. 2015. "Proposal for Teaching Evolutionary Biology: A Bridge between Research and Educational Practice." *Journal of Biological Education* 50 (2): 123–146.

Anderson, D., K. Fisher, and G. J. Norman. 2002. "Development and Evaluation of the Conceptual Inventory of Natural Selection." *Journal of Research in Science Teaching* 39: 952–978.

Banet, E., and G. E. Ayuso. 2003. "Teaching of Biological Inheritance and Evolution of Living Beings in Secondary School." *International Journal of Science Education* 25 (3): 373–407.

Bayer, C. N., and M. Luberda. 2016. "Measure, Then Show: Grasping Human Evolution through an Inquiry-based, Data-driven Hominin Skulls Lab." *PLoS ONE* 11 (8): e0160054. doi:10.1371/journal.pone.0160054.

Carter, B. E., and J. R Wiles. 2014. "Scientific Consensus and Social Controversy: Exploring Relationships between Students' Conceptions of the Nature of Science, Biological Evolution, and Global Climate Change." *Evolution: Education and Outreach* 7 (1): 6. doi:10.1186/s12052-014-0006-3.

Clough, M. 2006. "Learners' Responses to the Demands of Conceptual Change: Considerations for Effective Nature of Science Instruction." *Science & Education* 15 (5): 463–494.

Cofré, H., C. A. Vergara, N. G. Lederman, J. S. Lederman, D. P. Santibáñez, J. E. Jiménez, and M. A. Yancovic. 2014. "Improving Chilean In-service Elementary Teachers' Understanding of Nature of Science using Self-contained NOS and Content-embedded Mini-courses." *Journal of Science Teacher Education* 25 (7): 759–783.

Cofré, H., C. González-Weil, C. Vergara, D. Santibáñez, G. Ahumada, M. Furman, M. E. Podesta, J. Camacho, R. Gallego, and R. Pérez. 2015. "Science Teacher Education in South America: The Case of Argentina, Colombia and Chile." *Journal of Science Teacher Education* 26: 45–63.

Cofré, H., C. Vergara, D. Santibáñez, and J. P. Jiménez. 2013. "Una primera aproximación a la comprensión que tienen estudiantes universitarios en Chile de la Teoría de la Evolución." [An Initial Approach to Chilean Undergraduate Students' Understanding of Evolution Theory.] *Estudios Pedagógicos* 39: 7–26.

Cofré, H., J. Jiménez, D. Santibáñez, and C. Vergara. 2016. "Chilean Pre-service and In-service Teachers and Undergraduate Students' Understandings of Evolutionary Theory." *Journal of Biological Education* 50 (1): 10–23.

Coyne, J. A. 2010. *Why Evolution is True*. New York, NY: Viking.

Dagher, Z. R., and S. Boujaoude. 2005. "Students' Perceptions of the Nature of Evolutionary Theory." *Science Education* 89: 378–391.

Dobzhansky, T. 1973. "Nothing in Biology Makes Sense except in the Light of Evolution." *The American Biology Teacher* 35: 125–129.

Donnelly, D. F., B. Namdar, J. M. Vitale, K. Lai, and M. C. Linn. 2016. "Enhancing Student Explanations of Evolution: Comparing Elaborating and Competing Theory Prompts." *Journal of Research in Science Teaching* 53 (9): 1341–1363.

Emmons, N., H. Smith, and D. Kelemen. 2016. "Changing Minds with the Story of Adaptation: Strategies for Teaching Young Children about Natural Selection." *Early Education and Development*. 27: 1205–1221. doi:10.1080/10409289.2016.1169823.

Farber, P. 2003. "Teaching Evolution & the Nature of Science." *The American Biology Teacher* 65 (5): 347–354.

Field, A. 2011. *Discovering Statistics Using SPSS*. Sage.

Fischer, H. E., W. J. Boone, and K. Neumann. 2014. "Quantitative Research Designs and Approaches." In *Handbook of Research on Science Education*. Vol. II, edited by N. Lederman and S. Abell, 18–36. New York, NY: Routledge.

Fowler, S. R., and D. L. Zeidler. 2016. "Lack of Evolution Acceptance Inhibits Students' Negotiation of Biology-based Socioscientific Issues." *Journal of Biological Education* 50 (4): 407–424.

Futuyma, D. 2009. *Evolution*. Sunderland: Sinauer Associates.

Glaze, A. L., and M. J. Goldston. 2015. "U.S. Science Teaching and Learning of Evolution: A Critical Review of the Literature 2000–2014." *Science Education* 99 (3): 500–518.

Gonzalez-Galli, L., and E. Meinardi. 2015. "Obstáculos para el aprendizaje del modelo de evolución por selección natural, en estudiantes de escuela secundaria de Argentina." [Obstacles for Learning the Evolution Model by Natural Selection, in High School Students in Argentina.] *Ciência & Educação* 21 (1): 101–122.

Grant, P. 1999. "La selección natural y los pinzones de Darwin." [Natural Selection and Darwin Finches.] *Investigación Y Ciencia*. 60–65.

Ha, M., D. L. Haury, and R. H. Nehm. 2012. "Feeling of Certainty: Uncovering a Missing Link between Knowledge and Acceptance of Evolution." *Journal of Research in Science Teaching* 49: 95–121.

Ingram, C. J. E., C. A. Mulcare, Y. Itan, M. G. Thomas, and D. M. Swallow. 2009. "Lactose Digestion and the Evolutionary Genetics of Lactase Persistence." *Human Genetics* 124: 579–591.

Kampourakis, K., and W. F. McComas. 2010. "Charles Darwin and Evolution: Illustrating Human Aspects of Science." *Science & Education* 19 (6–8): 637–654.

Kampourakis, K., and V. Zogza. 2007. "Students' Preconceptions about Evolution: How Accurate is the Characterization as "Lamarckian" When Considering the History of Evolutionary Thought?" *Science & Education* 16: 393–422.

Khishfe, R., and N. Lederman. 2007. "Relationship between Instructional Context and Views of Nature of Science." *International Journal of Science Education* 29 (8): 939–961.

Kim, S., and K. Irving. 2009. "History of Science as an Instructional Context: Student Learning in Genetics and Nature of Science." *Science & Education* 19 (2): 187–215.

Kim, S. Y., and R. H. Nehm. 2010. "A Cross-cultural Comparison of Korean and American Science Teachers' Views of Evolution and the Nature of Science." *International Journal of Science Education* 10: 1–31.

Kim, S., and R. Nehm. 2011. "A Cross-cultural Comparison of Korean and American Science Teachers' Views of Evolution and the Nature of Science." *International Journal of Science Education* 33 (2): 197–227.

Lederman, N. G. 2007. "Nature of Science: Past, Present, and Future." In *Handbook of Research on Science Education*, edited by S. K. Abell and N. G. Lederman, 831–879. Mahwah, NJ: Lawrence Erlbaum.

Lederman, N. G., and F. Abd-El-Khalick. 1998. "Avoiding Denatured Science: Activities That Promote Understandings of the Nature of Science." In *The Nature of Science in Science Education: Rationales and Strategies*, edited by W. McComas, 83–126. Dordrecht: Kluwer.

Lederman, N. G., F. Abd-El-Khalick, R. Bell, and R. Schwartz. 2002. "Views of Nature of Science Questionnaire: Toward Valid and Meaningful Assessment of Learners' Conceptions of Nature of Science." *Journal of Research in Science Teaching* 39 (6): 497–521.

Lederman, N. G., and J. Lederman. 2014. "Research on Teaching and Learning of Nature of Science." In *Handbook of Research on Science Education*, edited by N. Lederman and S. Abell, 600–620. New York: Routledge.

Lederman, N. G., and R. Khishfe. 2002. *Views of Nature of Science, Form D*. Unpublished Paper. Chicago, IL: Illions Institute of Technology.

Lombrozo, T., A. Thanukos, and M. Weisberg. 2008. "The Importance of Understanding the Nature of Science for Accepting Evolution." *Evolution: Education and Outreach* 1 (3): 290–298.

Marín, C., and G. D'Elía. 2016. "Effect of Academic Degree and Discipline on Religious Beliefs and Evolution Acceptance: Survey at a Chilean University." *Zygon* 51 (2): 277–292.

McDonald, C. 2010. "The Influence of Explicit Nature of Science and Argumentation Instruction on Preservice Primary Teachers' Views of Nature of Science." *Journal of Research in Science Teaching* 47 (9): 1137–1164.

Medel, R. 2008. "The Evolution of Evolutionary Thinking in Chile." *Evolution: Education and Outreach* 1: 318–322.

Mesci, G., and R. Schwartz. 2017. "Changing Preservice Science Teachers' Views of Nature of Science: Why Some Conceptions May Be More Easily Altered than Others." *Research in Science Education* 47 (2): 329–351.

MINEDUC. 2009. *Ajuste curricular en Chile. Unidad de curriculum y evaluacion* [Curricular Adjustment in Chile. Curriculum and Assessment Unit]. Chile: Ministerio de Educación.

Mpeta, M., J. J. R. de Villiers, and W .J. Fraser. 2015. "Secondary School Learners' Response to the Teaching of Evolution in Limpopo Province, South Africa." *Journal of Biological Education* 49 (2): 150–164.

Nachman, M. W., H. E. Hoekstra, and S. L. D'Agostino. 2003. "The Genetic Basis of Adaptive Melanism in Pocket Mice." *Proceedings of the National Academy of Sciences* 100 (9): 5268–5273.

Nadelson, L. S., and K. Hardy. 2015. "Trust in Science and Scientists and the Acceptance of Evolution." *Evolution: Education and Outreach* 8: 9. doi:10.1186/s12052-015-0037-4.

Nadelson, L. S., and G. M. Sinatra. 2010. "Shifting Acceptance of Evolution: Promising Evidence of the Influence of the "Understanding Evolution" Webside." *The Researcher* 23 (1): 13–29.

Nehm, R. H., E. P. Beggrow, J. E. Opfer, and M. Ha. 2012. "Reasoning About Natural Selection: Diagnosing Contextual Competency Using the ACORNS Instrument." *The American Biology Teacher* 74 (2): 92–98.

Nehm, R. H., S. Kim, and K. Sheppard. 2009. "Academic Preparation in Biology and Advocacy for Teaching Evolution: Biology versus Non-biology Teachers." *Science Education* 93: 1122–1146.

Nehm, R. H., and I. S. Schonfeld. 2007. "Does Increasing Biology Teacher Knowledge of Evolution and the Nature of Science Lead to Greater Preference for the Teaching of Evolution in Schools?" *Journal of Research Science Teaching* 18: 699–723.

Nunez, E. E., R. M. Pringle, and K. T. Showalter. 2012. "Evolution in the Caribbean Classroom: A Critical Analysis of the Role of Biology Teachers and Science Standards in Shaping Evolution Instruction in Belize." *International Journal of Science Education* 34: 2421–2453.

Pazza, R., P. R. Penteado, and K. F. Kavalco. 2010. "Misconceptions about Evolution in Brazilian Freshmen Students." *Evolution: Education and Outreach* 3: 107–113.

Peters, E. 2012. "Developing Content Knowledge in Students through Explicit Teaching of the Nature of Science: Influences of Goal Setting and Self-monitoring." *Science & Education* 21: 881–898.

Pramling, N. 2009. "The Role of Metaphor in Darwin and the Implications for Teaching Evolution." *Science Education* 93: 535–547.

Robbins, J. R., and P. Roy. 2007. "The Natural Selection: Identifying & Correcting Non-Science Student Preconceptions through an Inquiry-based, Critical Approach to Evolution." *The American Biology Teacher* 69: 460–466.

Rudge, D. W., and E. Howe. 2009. "An Explicit and Reflective Approach to the Use of History to Promote Understanding of the Nature of Science." *Science & Education* 18 (5): 561–580.

Rutledge, M. L., and K. C. Sadler. 2011. "University Students' Acceptance of Biological Theories – Is Evolution Really Different?" *Journal of College Science Teaching* 41 (2): 38–43.

Rutledge, M. L., and M. A. Mitchell. 2002. "High School Biology Teachers' Knowledge Structure, Acceptance and Teaching of Evolution." *The American Biology Teacher* 64 (1): 21–28.

Rutledge, M. L., and M. A. Warden. 2000. "Evolutionary Theory, the Nature of Science & High School Biology Teachers: Critical Relationships." *The American Biology Teacher* 62: 23–31.

Sickel, A. J., and P. Friedrichsen. 2013. "Examining the Evolution Education Literature with a Focus on Teachers: Major Findings, Goals for Teacher Preparation, and Directions for Future Research." *Evolution: Education and Outreach* 6 (1): 23.

Sinatra, G. M., S. A. Southerland, F. McConaughy, and J. W. Demastes. 2003. "Intentions and Beliefs in Students' Understanding and Acceptance of Biological Evolution." *Journal of Research in Science Teaching* 40: 510–528.

Taşkın, Ö. 2013. "Pre-service Science Teachers' Acceptance of Biological Evolution in Turkey." *Journal of Biological Education* 47: 200–207.