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The relationship between biology teachers' understanding of the nature of science and the understanding and acceptance of the theory of evolution

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ABSTRACT

Despite the importance of the theory of evolution (TE) to scientific knowledge, a number of misconceptions continue to be found among biology teachers. In this context, the first objective of this study was to identify the impact of professional development programme (PDP) on teachers' understanding of nature of science (NOS) and evolution and on the acceptance of this theory. Its second objective was to study the relationship among these variables. Three instruments were used to quantify these variables: the Views of the Nature of Science Version D (VNOS D+), the Assessing Contextual Reasoning about Natural Selection (ACORN), and the Measure of Acceptance of Theory of Evolution (MATE). The results indicate that the PDP had a positive impact on teachers, significantly improving their understanding of the NOS and natural selection, as well as their acceptance of the TE. Furthermore, a positive correlation between the understanding of the NOS obtained by teachers in the first part of the PDP and the understanding and acceptance of evolution that these teachers showed at the end of the programme was determined. However, no relationship between an understanding of the NOS and gains in the understanding and acceptance of evolution was found.

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Professional development programme; NOS; theory of evolution

Introduction

The theory of evolution (TE hereafter) has been described as one of the most consistent and unifying theoretical entities in biology, capable of explaining a large number of natural phenomena at different scales and with different types of evidence (Coyne, 2010; Dobzhansky, 1973; Futuyma, 2009). Furthermore, an understanding of this biological theoretical framework turns students into active citizens who can form opinions and resolve problems at the local level. For example, they are able to understand certain illnesses of our time, explain human behaviour, or comprehend why some types of species are more at threat of becoming extinct. Therefore, knowledge of evolution is indispensable for scientific literacy (Glaze & Goldston, 2015). Nonetheless, studies conducted with high school students reveal that many of them have little or no knowledge concerning evolution. In learning evaluations, they tend to retain only the information that is

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necessary to pass exams and then return to their old beliefs (Nehm & Schonfeld, 2007). Therefore, students often graduate with misconceptions, such as the notion that evolution is the activity of an organism's internal forces and that these change out of necessity and in response to the environment (Cofré et al., 2013; Kampourakis & Zogza, 2007). Furthermore, students' personal beliefs define the manner in which they view the world and potentially influence the quality of their learning experience (Cavallo & McCall, 2014). Such personal beliefs affect not only student's understanding of the TE but also their acceptance of it.

Additionally, there is ample evidence that biology teachers also have difficulty accepting evolutionary knowledge as valid (Kim & Nehm, 2011). A review conducted by these authors shows that biology teachers' acceptance of the TE in countries such as the United States and Turkey does not exceed 60%. European countries show higher levels of acceptance of the theory. Nonetheless, rejection levels are approximately 20% in countries such as Germany and England. In addition, there is a large amount of evidence suggesting that problems pertaining to the acceptance and understanding of the TE in classrooms are directly related to the beliefs, limitations, and insecurities of the biology teachers themselves (Glaze & Goldston, 2015; Romine, Barnett, Friedrichsen, & Sickel, 2014; Sickel & Friedrichsen, 2013). For example, Griffith and Brem (2004) describe situations in which teachers restrict content and choose the aspects of evolution that they will impart to students because this strategy allows them to remain in their comfort zone and avoid questions that they do not feel capable of answering.

On the other hand, it has been suggested that knowledge regarding the nature of science (NOS hereafter) (how scientific knowledge is generated and tested and how scientists do what they do [Lederman & Lederman, 2014]) is a fundamental means of generating knowledge on evolution and its acceptance in both teachers and students (Glaze & Goldston, 2015; Sickel & Friedrichsen, 2013). For example, in a study conducted in the United States with 640 students, it was concluded that there is a positive correlation between changes in conceptions of NOS and changes in students' attitudes towards the TE (Carter & Wiles, 2014). It has been shown that NOS provides key concepts that lead to an understanding of science and the generation of scientific knowledge, the concept of theory, the diversity of research methods used, and the role of inference and observation in science. One way or another, all of these concepts can affect students' and teachers' views on the TE (Dagher & BouJaoude, 2005; Glaze & Goldston, 2015; Sickel & Friedrichsen, 2013).

These findings have led some authors to propose a strong relationship between the NOS and understanding and accepting evolution (Akyol, Tekkaya, Sungur, & Traynor, 2012; Lombrozo, Thanukos, & Weisberg, 2008). However, other authors have claimed that this relationship is unclear (Cofré et al., 2013; Ha, Baldwin, & Nehm, 2015). Despite this lack of conclusive results, few studies focus on disentangling these relationships in students (Cofré et al., 2017) or teachers (Ha et al., 2015). Consequently, more investigations are critically needed to determine the impact of instructional strategies that incorporate the NOS for teaching evolution (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Ha et al., 2015; Nehm & Schonfeld, 2007; Scharmann, Smith, James, & Jensen, 2005). In this context, the main objective of this study is dual. On one hand, it is to analyse the effectiveness of a professional development programme (PDP) in teachers' understanding of evolution, acceptance of evolution, and understanding of the

NOS. On the other hand, it is to investigate the relationship between teachers' understanding of the NOS and their understanding and acceptance of the TE.

Teachers' understanding of NOS and its relationship to knowledge and acceptance of TE

For Lederman (2007), NOS should be defined as 'the characteristics of scientific knowledge that are directly related to the way in which it is reproduced', and worldwide, it is considered a vital component for the development of scientific literacy (American Association for the Advancement of Science, 1990). Nonetheless, it is known that science teachers around the world uphold misconceptions and mistaken beliefs regarding subjects pertaining to the NOS (Cofré et al., 2014a, Pavez et al., 2016; Lederman, 2007; Lederman & Lederman, 2014). Furthermore, it has been proposed that NOS may be a facilitating component for learning complex scientific concepts. However, little empirical evidence exists to support this hypothesis (Lederman, 2007). Some of the few examples of this type of research are the studies by Songer and Linn (1991), for whom students with greater knowledge of NOS show better learning of thermo-dynamic content, and Peters (2012), who shows that students in physics classes that incorporated NOS learn more about electricity and magnetism than students to whom NOS was not imparted.

In the field of biology (see McComas, 2015), there is some evidence that preconceptions regarding NOS in the context of TE, for example, saying that 'Evolution is only a theory', can be negatively related to knowledge and acceptance of evolution (e.g. Dagher & Bou-Jaoude, 2005; Glaze & Goldston, 2015; Ha et al., 2015; Kim & Nehm, 2011; National Academy of Sciences [NAS], 1998; Sickel & Friedrichsen, 2013). It has been shown that teachers with more knowledge of NOS are more willing to teach TE (Rutledge & Mitchell, 2002; Rutledge & Warden, 2000). Some of the topics within NOS are the difference between theory and law as well as the idea that knowledge can be tested and that science is not static. These aspects could be key to teachers' understanding of evolutionary theory as a collection of robust principles versus an idea that has not been proven and has yet to become a law. For example, an understanding that scientific knowledge is not static would help teachers understand that TE has been changing and can be modified based on future evidence (Sickel & Friedrichsen, 2013).

Despite this reasonable proposal of a relationship between NOS and evolution variables, most of the evidence supporting these results comes from quantitative correlational studies; consequently, it is difficult to assume causal relationships (Ha et al., 2015). Specifically, some studies have found a positive correlation between teachers' understanding of NOS and their knowledge and acceptance of evolution (Akyol et al., 2012; Dagher & Bou-Jaoude, 2005; Ha et al., 2015; Kim & Nehm, 2011; Lombrozo et al., 2008; Nehm et al., 2009; Rutledge & Mitchell, 2002). To explain this relationship, Rutledge and Mitchell (2002) propose that teachers with naïve views on NOS are incapable of distinguishing between the scientific validity of evolution and religious beliefs. In another study, Akyol et al. (2012) find a significant positive relationship between pre-service science teachers' views of NOS and their acceptance of the TE. In that study, which included 415 pre-service science teachers, participants with more sophisticated views on the NOS tended to accept evolution more than other participants. In another recent study including 28 teachers (18 elementary school teachers and 10 secondary science teachers), Ha et al. (2015)

find a robust ($r > 0.6$) and significant correlation between knowledge and acceptance of evolution and the understanding of NOS, but they note that the correlations among the learning gain scores for these variables, after instruction, were not significant. In a more qualitative study conducted with university students, Dagher and BouJaoude (2005) show that students who were uncertain about the TE held misconceptions such as 'the theory of evolution is not supported by concrete evidence', 'evolution has not yet been proven like cell theory', and 'the theory of evolution lacks experimentation', among others.

Nonetheless, other studies have failed to demonstrate a positive relationship between the understanding of NOS and accepting or understanding of evolution (e.g. Athanasiou, Katakos, & Papadopoulou, 2016; Cofré et al., 2013; Cho, Lankford, & Wescott, 2011; Sinatra, Southerland, McConaughy, & Demastes, 2003). For example, in a study including 318 teachers from Greece, Athanasiou et al., (2016) do not find a strong relationship between the understanding of NOS and the understanding of evolution ($r = -0.013$) or the acceptance of evolution ($r = 0.114$), although this last relationship is significant. However, when the variables are studied within different groups of teachers (elementary, biology, and geology teachers), a positive and significant correlation between the understanding of NOS and the acceptance of the TE presented by geology teachers ($r = 0.504$, $p < .05$) is found. According to this literature review, the relationship between NOS and the acceptance and knowledge of evolution is still very difficult to disentangle.

Professional development programmes in evolutionary theory

There is sufficient evidence showing that many science teachers around the world (including biology teachers) have problems in both understanding TE (particularly the mechanism of natural selection) and accepting it as valid scientific knowledge (e.g. Athanasiou et al., 2016; Cofré et al., 2016; Ha et al., 2015; Kim & Nehm, 2011; Nunez, Pringle, & Showalter, 2012; van Dijk, 2009); therefore, they also have many problems teaching this biological content (Glaze & Goldston, 2015; Sickel & Friedrichsen, 2013). Some of the limitations that make it difficult for biology teachers to correctly impart knowledge of evolution that have been identified are weak preparation in content pertaining to evolution in their initial training, little understanding regarding what the NOS is (see previous section), lack of training in instructional strategies for teaching evolution (or pedagogical content knowledge [PCK] of evolution), and the inability to stand up under the pressure of the academic community (representatives and directors) when attempting to teach alternative explanations (e.g. Glaze & Goldston, 2015; Ha et al., 2015; Kim & Nehm, 2011; Lombrozo et al., 2008; Romine et al., 2014; Sickel & Friedrichsen, 2013; van Dijk, 2009). For example, in a qualitative study, van Dijk (2009) finds that a group of nine biology teachers in Germany know many of the problems, limitations, and misconceptions concerning TE that students hold but have some problems with the nature of evolutionary biology. Specifically, some of the teachers recognise that 'evolution has no evidence' or 'evolution is soft' or 'is just a theory'. On the other hand, in a study focusing on describing the professional development needs of 276 biology teachers, Romine et al. (2014) find that obstacles to teaching evolution (e.g. misconceptions), school and community support for evolution instruction, confidence in evolution instruction, and prior coursework in evolution are the main needs of teachers.

Despite these conclusions, there are few studies that address the implementation of PDPs that focus on improving the knowledge and acceptance of evolution in practising biology teachers (e.g. Bravo & Cofre 2016; Crawford et al., 2005; Ha et al., 2015; Nehm & Schonfeld, 2007). Therefore, there is a real need to investigate the characteristics that these PDPs should have to be effective in the development of teachers' knowledge and acceptance. In a review of the literature on science teachers' understanding and teaching of evolution, Sickel and Friedrichsen (2013) propose five goals for training teachers to impart TE. These goals consist of five areas of teaching: (a) knowledge of evolutionary content (subject matter knowledge of evolution), (b) NOS, (c) acceptance of evolutionary theory, (d) controversies that arise when teaching evolution, and (e) PCK of evolution. These components would make it possible to effectively implement a development programme for teachers. Empirical evidence of these recommendations is the result from a recent study published by Ha et al. (2015). In a short-term PDP including 28 teachers (18 elementary and 10 secondary science teachers), these authors report sustained large effect sizes for both knowledge and acceptance of evolution 1.5 years after programme completion.

Research questions

In accordance with the literature previously reviewed in this study, a PDP for biology teachers that included several elements that have been described as desirable for performing work that is effective in developing teachers' content knowledge and PCK was implemented (Ha et al., 2015; Sickel & Friedrichsen, 2013). The following questions guided this study:

- What is the impact of the implementation of a PDP on teachers' knowledge of NOS and knowledge and acceptance of TE?
- What is the relationship between biology teachers' learning gains for evolution content knowledge and learning gains for the NOS? Are these learning gains associated with biology teachers' changes in acceptance?

Methodology

Research design

This study is quantitative in nature, with a transversal, non-experimental, correlational study design, with a pre–posttest data collection procedure (Fischer, Boone, & Neumann, 2014). Given the nature of the PDP, we did not establish a control group; consequently, our study design prohibits making causal claims but provides rich information on the associations between the intervention variables (NOS knowledge, and TE knowledge and acceptance). Figure 1 shows the intervention schedule and the timing of the instrument applications.

Research context and participants

Several studies at the international level have shown that a significant number of teachers are not certain about the principles underlying TE or simply do not accept it (Sickel &

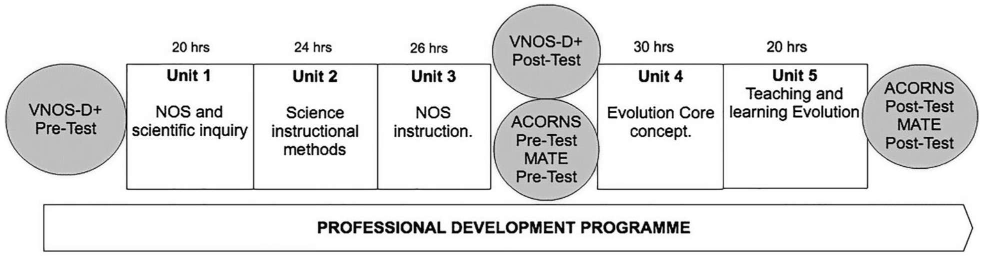

Figure 1. Structure and chronological order of the Professional Development Programme (PDP), which was implemented in the same way in 2013, 2014, and 2015.

Friedrichsen, 2013). However, a study conducted in Chile with 120 biology teachers and future biology teachers shows that 80% of working teachers and close to 70% of pre-service teachers agree with the proposal that evolution is a scientific fact (Cofré et al., 2013, 2016), which coincides with the highest levels of acceptance found in European countries (Kim & Nehm, 2011). On the issue of understanding evolution, the same group of Chilean teachers shows that close to half of the participants reveal misconceptions, in which the most common answers regarding the mechanism of evolution tend towards Lamarckian and, in particular, theological propositions (Cofré et al., 2016; Kampourakis & Zogza, 2007). On the other hand, according to recent studies (for more details, see Cofré et al., 2014; Pavez et al., 2016), the elementary teachers and biology secondary teachers studied are typically poorly informed about NOS.

The participants of the present study included 31 biology teachers, representing three cohorts or generations that participated in a six-month PDP focused on NOS and evolution. Fifteen biology teachers participated in the PDP in 2013, eight teachers in 2014, and eight teachers in 2015. Most of the teachers who participated in the PDP taught at the secondary level, but six mostly taught at the middle school level. Regarding the teachers' experience teaching science, the majority of them (18 teachers) had less than five years working in schools. Seven biology teachers had between 6 and 10 years of experience, and finally, six teachers had between 11 and 20 years of experience teaching biology and the natural sciences. Most of the teachers participating in the PDP (25) studied in an undergraduate science teacher programme that had concurrent instruction, including both disciplinary and pedagogical training from the first year (Cofré et al., 2015). In contrast, a small group of participating biology teachers first concluded a scientific career and then studied pedagogy for only one year to obtain a biology teacher certification.

Professional development programme

This study was conducted within the context of a National Science Foundation Project in Chile (FONDECYT) that included the implementation of a six-month PDP during three consecutive years, 2013, 2014, and 2015, at a private university in Santiago, Chile (see Figure 1). Each year, the participants attended a five-hour class every Saturday between August and November and for one intensive week in January (the following year). The total number of class hours was 120, and these hours were distributed between five units: Unit 1, NOS and scientific inquiry; Unit 2, science instructional methods; Unit 3, NOS instruction; Unit 4, evolution core concept; and Unit 5, teaching and learning evolution. Table 1 shows the details of the curriculum implemented in each of the programme units. In addition, we describe examples of activities performed in each (for details concerning some lessons on NOS using the history of biology, see also Pavez et al., 2016).

Based on other successful experiences (Bayer & Luberda, 2016; Ha et al., 2015; Lederman, Lederman, Kim, & Ko, 2012), the curriculum content was delivered using a pedagogical approach based on active learning. The PDP focused on creating many opportunities for improving teachers' content knowledge and PCK through workshops. In these sessions, many activities in which teachers readily engaged with the scientific process of data analysis were included. The workshops included argumentation activities; prediction,

Table 1. Overview of the units, intervention topics, activities, and readings used in the teacher professional development programme (for see more activities, and more detail Cofré resources showed here, see also Cofré et al., 2014, Pavez et al., 2016).

Unit	Topics	Activities examples	Readings and reflections
1. NOS and scientific inquiry	This unit covers the aim of scientific literacy, and the concept of NOS and scientific inquiry	• Magic tube; tricky tracks; and other decontextualised NOS activities with reflective discussion • Analysis of data from scientific paper about Chilean birds ecology in contextualised NOS activities	Cofré (2012), Vergara & Cofré (2012), Lederman and Lederman (2010), Vilina and Cofré (2000)
2. Science instructional methods	Unit 2 covers science instructional methods, including the use of models, and conceptual change theory	• Conceptual change activity • Inquiry lab about *Daphnia* population growth with reflective discussion • Lesson planning of inquiry-based lessons	Kruger and Upmeier (2010), Puig, Bravo, and Jiménez Aleixandre (2012), Chamizo (2010)
3. NOS Instruction	Unit three covers the teaching of NOS, including the use of History of science (Author et al., 2016b), scientific inquiry and argumentation	• Video: Malaria and sickle cell anaemia (from Howard Hughes Medical Institute [HHMI], available at https://www.youtube.com/user/Biointeractive) • Contextualised NOS activities including History of Science • Microteaching session about teaching NOS in context of biology lesson	Cofré (2012), Ledermam and Lederman (2004), Clough (2011)
4. Evolution core concept	Unit four covers mostly core evolution content such as: natural selection, human evolution, and the diversity of extant and extinct mammals of Chile	• Videos: The evolution of lactose tolerance; Galapagos Finch evolution; natural selection and the rock pocket mouse (from HHMI) used in POE activities • Inquiry -based activities including history of evolution • Computer lab about skin colour evolution in humans	Cofré et al. (2014), Flyn, Wyss, and Charrier (2007), Nachman and Hoekstra (2003), Spotorno (2014), Grant (1999), Trut (1999), Jablonski and Chaplin (2002)
5. Teaching and learning evolution	The last unit addresses mostly evolution instruction, including preconceptions regarding evolution, teaching strategies, evolution in normal life context, and the importance of NOS for understanding and teaching evolution	• Inquiry -based activities about human evolution • Papers discussion about PCK in evolution • Microteaching session about teaching Evolution including NOS or inquiry	Cofré et al. (2013), Gonzalez-Galli andMeinardi (2015), Agnew and Demas (1998)

observation, and explanation (POE) activities; case study activities; and inquiry lab activities (Table 1).

In the first units (Units 1 to 3), NOS instruction was delivered in an explicit and reflective manner (Lederman, 2007). The lessons included both decontextualised and contextualised activities that focused the students' attention on some particular NOS aspects. In the last units (Units 4–5), the lessons concerning evolution focused on teachers' learning about the three essential components of natural selection: variation, differential fitness (reproduction and survival), and inheritance (Futuyma, 2009). Most of the activities (see Table 1) included a working guide. In each lesson, questions that asked students to reflect on different aspects of the nature of evolutionary knowledge were also included, with a focus on teachers' working to turn empirical data into knowledge and knowledge into acceptance (Bayer & Luberda, 2016).

Instruments and data collection

The instrument used to evaluate teachers' understanding of NOS before and after the intervention was the Views of the Nature of Science Version D (VNOS-D+) questionnaire (Lederman & Khishfe, 2002). This questionnaire was chosen because it clearly evaluates aspects of the NOS (Abd-El-Khalick, 2014) and because the VNOS has already been used in other studies to examine the relationship between the understanding of the NOS and an understanding of evolution (e.g. Ha et al., 2015; Kim & Nehm, 2011). Furthermore, this instrument has been used and validated in previous studies in which Chilean teachers participated (Cofré et al., 2014, 2016).

The Measure of Acceptance of Theory of Evolution (MATE) questionnaire, developed by Rutledge and Warden (2000), was used to evaluate the degree of acceptance of evolutionary theory by teachers. This questionnaire contains 20 Likert scale questions that address six subjects, including human evolution and the scientific validity of evolutionary theory. This instrument was applied because it is one of the most commonly used instruments in the international literature and because it has been shown to be highly reliable (Fowler & Zeidler, 2016; Ha et al., 2015; Nadelson & Sinatra, 2010; Rutledge & Warden, 2000). Furthermore, it has also been used in studies that include Chilean teachers and students and has therefore been translated and validated in Spanish (Cofré et al., 2017).

To evaluate teachers' knowledge of the mechanism of natural selection, the Assessing Contextual Reasoning about Natural Selection (ACORNS) questionnaire (Nehm, Beggrow, Opfer, & Ha, 2012) was used, which is one of the most commonly used questionnaires in the literature for measuring knowledge of evolution (Ha et al., 2015) and has been found to be highly reliable and valid (Nehm et al., 2012). Additionally, similar to the MATE questionnaire, the ACORNS instrument has been used in studies that include Chilean teachers and has therefore been translated and validated in Spanish (Cofré et al., 2017).

Data analysis

The responses to the ACORNS questionnaire were analysed based on a modification of the rubric created by Nehm et al. (2012) in which both wrong answers and preconceptions are recognised, in addition to key or correct concepts associated with the mechanism of natural selection. The key concept scores for each response ranged from 0 to 10, and the misconception scores ranged from 0 to 6. Considering that the test included four questions, a maximum of 40 points could be obtained for correct responses and a total of 24 points for ingenuous or incorrect responses. Two researchers conducted the analysis of all participant responses. The kappa values for inter-rater reliability were between 0.75 and 0.90 for all key concepts and alternative conceptions in each teacher cohort and in the pre- and posttest applications. Consensus scores were arrived at when discrepancies arose. Some examples of the teachers' responses are shown in Table 1.

The VNOS-D+ questionnaire contains eight questions that evaluate eight aspects of NOS. The responses from the pre- and posttest of this questionnaire were classified in a rubric as 'informed', 'mixed', or 'naïve' knowledge. The response was classified as 'informed' when it was clearly aligned with the recommended vision for each aspect of NOS (Lederman & Khishfe, 2002). When the response was aligned with the recommended position but was not completely developed and possessed some wrong concepts, it was classified as 'mixed'. When the teacher's response was not aligned with the exact position of that which was expected of the aspects of NOS, it was classified as 'naïve'. The responses were analysed separately by two researchers. The kappa values for inter-rater reliability were between 0.70 and 0.85 for all aspects together in each teacher cohort and in the pre- and posttest applications. Then, the two researchers worked together to agree upon the classification of responses for which disagreements existed. With the objective of conducting a quantitative analysis for each of the responses, these were assigned values: 2 points for informed responses, 1 for mixed responses, and 0 for naïve responses. The values of each aspect were summed to obtain a total value for the knowledge of NOS variable. Because there were eight aspects of NOS that were evaluated, the range of points that could be obtained was from 0 (naïve for all aspects) to 16 (informed for all aspects).

Regarding the quantitative analysis of the MATE questionnaire, a value was assigned to each of the 20 Likert scale questions. When the response was one of low TE acceptance, it was given 1 point, whereas high acceptance responses were given 5 points. The scores ranged from 20 to 100 points, indicating low or high acceptance, respectively. Although it has recently been described that the MATE questionnaire can be analysed by recognising two dimensions (Romine, Walter, Bosse, & Todd, 2017), we have maintained the traditional analysis of the instrument to compare our results with those of previously published studies.

To determine whether there was a significant difference between the pre- and posttest result of each variable, the Wilcoxon signed-rank test was used (Field, 2011), and Spearman's correlation index was used to determine the relations between variables (knowledge of NOS, the TE, and acceptance). The effect size for all analyses was also calculated (Field, 2011).

All statistical analyses were conducted using SPSS version 19. The variable values that were used to analyse these correlations were those that corresponded with the NOS posttests and the knowledge and acceptance of evolution posttests, in addition to the gains in knowledge regarding the NOS and evolution and the gains in the acceptance of evolution.

Results

Understanding of NOS

Regarding the understanding of NOS, in a comparison of the pre- and posttest results (Figure 2), there was an increase in teachers' scores regarding the NOS following their completion of the first units of the PDP. On average, teachers' knowledge increased 5.13 points, from an average of 8.26 to 13.39 points. A Wilcoxon signed-rank test indicated that the posttest value of the understanding of NOS was significantly higher than the pretest value ($z = -4.84$; $p < .001$; $r = -0.62$).

Understanding of evolution

Concerning the results obtained regarding the understanding of evolution, considerable knowledge gains can be observed (Figure 3). The results regarding previous knowledge show an average value of 2.71 points. Considering that the maximum score was 40 points, these results were low. After having completed the PDP, the average value of the understanding of evolution was 11.23 points. The Wilcoxon signed-rank test indicates that the posttest value of knowledge of evolution was significantly higher than the pretest value ($z = -4.50$; $p < .001$; $r = -0.58$). Table 2 shows examples of some teachers' responses before and after the PDP. In general, most of the biology teachers held a very low understanding of the process of natural selection; however, at the end of this experience, many of them left behind their teleological thoughts or at least included more key concepts in their explanation.

Acceptance of evolution

In the case of the acceptance of the TE, an average gain of 12.94 points was observed (Figure 4). It is important to note that, on average, the pre- and posttest values were

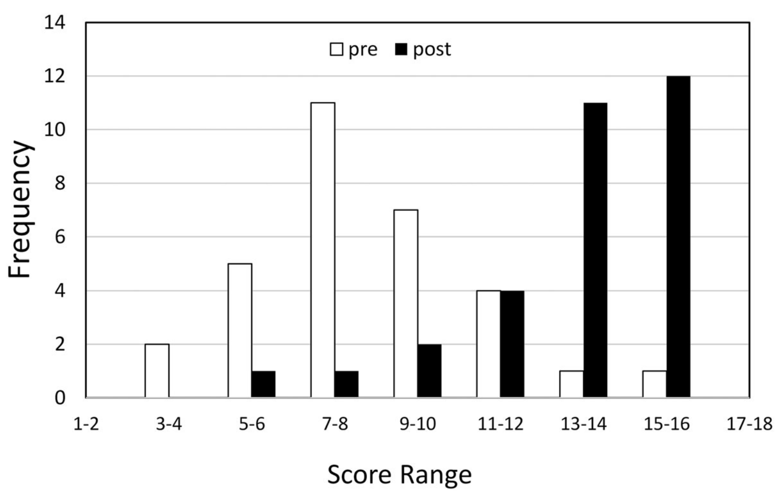

Figure 2. Graph of the frequency distribution of the pre and post knowledge of the NOS in teachers who participated in a professional development programme.

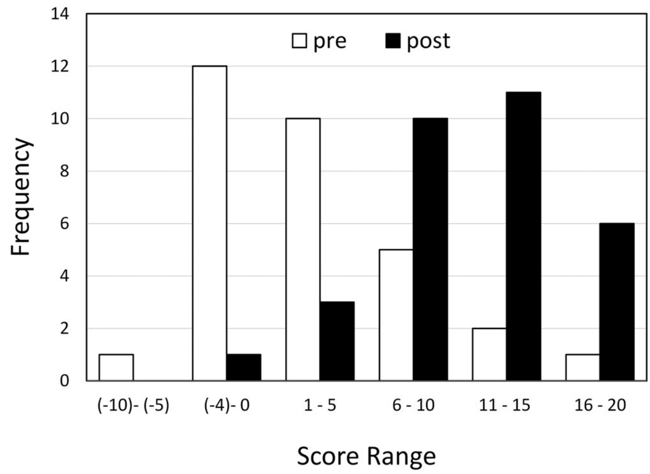

Figure 3. Graph of the frequency distribution of pre and post knowledge of evolution in teachers who participated in a professional development programme.

high, 77.52 and 90.45, respectively. The Wilcoxon signed-rank test indicates that the posttest value of the acceptance of evolution was significantly higher than the pretest value ($z = -4.73$; $p < .001$; $r = -0.62$).

Relationships between variables

To analyse the relationships among variables, a correlation analysis between NOS, the understanding of evolution, and the acceptance of evolution was conducted, in which the posttest values and the gains obtained from each of the variables were used. From all of the correlations obtained (Table 3), it can be observed that only some of them are significant. Specifically, the clearest tendency is that both the final knowledge of NOS

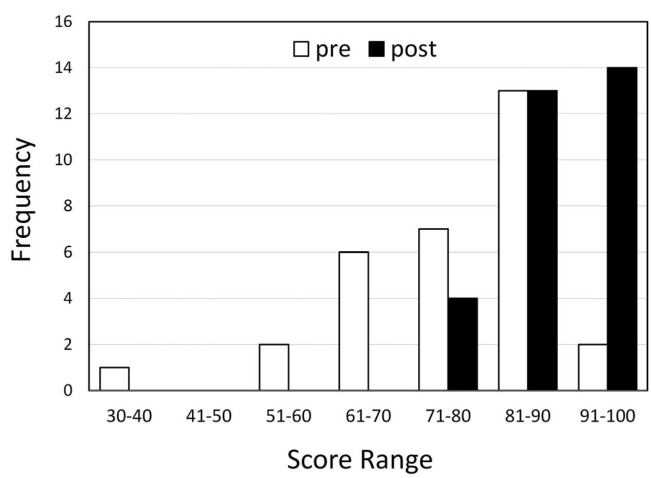

Figure 4. Graph of the frequency distribution of pre and post acceptance of the theory of evolution in teachers who participated in a professional development programme.

Table 2. Examples of teachers' responses, and its analysis and scoring.

Example of teachers' responses to the question: How do you think biologists explain the mechanism by which the species *Homo sapiens* has evolved towards body hair loss, a trait that most hominid ancestors seemed to have?	Correct answer type	Score (+)	Wrong answer type	Score (−)	Final answer	Final score
The fact that *Homo sapiens* does not have body hair today can be explained *by the simple necessity of wearing clothes*. This has led *Homo sapiens* not to have the need for a coat (something that gives hair)			*Incomplete Lamarckian & Teleological*	2	*Incomplete Lamarckian& Teleological*	−2
This feature can be explained through the changes that have occurred in the environment in which they existed; this trait was therefore the product of a mutation of this trait	Incomplete Darwinian	1	*Teleological*	1	Mixed	0
In the ancestor, the body hair trait must have presented variables that allowed it to develop hair in the body to a greater or lesser extent. When the environment exerted a selective pressure that conferred a greater reproductive advantage to those individuals of the population who had less body hair (as might have been the degree of attraction that this meant in the pair choice, for example), they increased their fitness, and the proportion of them increased in the population because that characteristic was inherited by the offspring	Complete Darwinian	5			Complete Darwinian	5

Example of teachers' responses to the question: How do you think biologists explain the mechanism of how a current rose species that has thorns evolved from an ancestral rose that showed no thorns?	Correct answer type	Score (+)	Wrong answer type	Score (−)	*Final classification*	Final score
According to their needs, the roses formerly needed to release so much water and, in doing so, developed this mechanism of thorns to retain more water			Teleological	2	Teleological	−2
From an ancestral rose that did not show thorns, *an individual began to present some indication of the thorns,* and this species was apt to survive and perpetuate the species, and so it was modified until arriving at the present rose with thorns	Incomplete Darwinian	1	*Teleological*	1	Mixed	0
In this case, the pressure of selection or the factor that triggered natural selection is that of predators; roses that had spines were less predated than those without spines due to the possibility that survival and reproduction are greater and inheriting the characteristic and maintaining it with success increase its frequency in the population	Complete Darwinian	4				4

and the NOS knowledge gains are positively and significantly related to the variables studied for evolutionary knowledge and acceptance (Table 3). However, this positive and significant relationship between NOS (post value or gains knowledge) and the gained knowledge of evolution or its gained acceptance is not observed.

Discussion

Effectiveness of the PDP implementation

One of the central objectives of this study was to analyse the effectiveness of a PDP in teachers' understanding and acceptance of evolution and understanding of NOS. According to Sickel and Friedrichsen (2013), the implementation of training programmes in evolution is not abundant in the literature, showing both positive and no impact on teachers' understanding and acceptance of evolution and willingness to teach evolution. In the present study, we show a very high impact of the programme on the three variables studied. Our results are even better than the results reported by Ha et al. (2015), who show a large effect for the NOS and gains in the knowledge of evolution and evolution acceptance. The present study reports a larger increase in the acceptance and understanding of natural selection assessed with the same instrument used by Ha et al. (2015). Although both programmes share many good traits, such as a strong focus on subject matter knowledge of evolution, teaching explicitly, a long duration, and inquiry-based pedagogy focused on empirical evidence of evolution, our programme had a more explicit work concerning PCK for evolution than other studies (such as those of Crawford et al., 2005; Ha et al., 2015).

Relationship between teachers' understanding of NOS and evolution

Regarding the results obtained from the correlation of the variables of teachers' understanding of NOS post with the knowledge of evolution post and the gain in knowledge of evolution, very different values were obtained, pointing to different interpretations. In the case of NOS post with evolution post, the correlation was positive and significant, which is in accordance with the findings from some studies in the literature (e.g. Akyol et al., 2012; Ha et al., 2015; Kim & Nehm, 2011; Lombrozo et al., 2008; Rutledge & Warden, 2000). Interestingly, the results obtained regarding the correlation of knowledge of the NOS posttest with the gain in evolution knowledge contrast with the results noted above, given that no significant correlation was found. This result indicates that knowledge of NOS was not related to the knowledge of evolution gained during the course. One possible explanation for this result is that some of the teachers who participated in the programme already had significant knowledge of evolution. This meant that the knowledge that they gained was minimal even though their understanding of NOS was high. This resulted in a limited relationship between variables. Therefore, an alternative hypothesis that emerges from this finding is the importance of other latent variables in explaining the gains in knowledge of evolution, such as teachers' previous knowledge or religious beliefs. Additionally, it is very interesting to note that these results were obtained in a recent study by Ha et al. (2015), who also found a significant relationship between NOS and knowledge of evolution; however, they did not find any relationship between their gain obtained in the PDP.

Relationship between teachers' understanding of NOS and their acceptance of evolution

The correlation that exists between teachers' understanding of NOS post and the MATE score post is shown to be positive and significant. However, as occurs with the analysis of the understanding of evolution, when gains in acceptance (MATE) are compared with NOS post values, a very different result emerges, and no relationship exists at all. We can explain this lack of correlation as a result of the fact that the majority of the teachers begin the programme with high MATE scores. For this reason, it is inevitable that their gains will be low compared to the high values obtained in NOS after the PDP, resulting in a null correlation. In the current literature, these results suggest that greater precaution should be exercised when interpreting the results of studies that are a photograph and that compare knowledge of NOS and acceptance of evolution (e.g. Kim & Nehm, 2011; Lombrozo et al., 2008; Rutledge & Warden, 2000). This research is the second study in the literature that relates teachers' knowledge of NOS and evolution and their acceptance of evolution following a training programme and in which it is observed that the understanding of NOS does not appear to explain teachers' learning or gains in acceptance of evolution, meaning that the relationship between these variables may be more complex (Ha et al., 2015).

Conclusions, limitations, and future research

Based on the results of this study and in response to the first research question, it is concluded that the implementation of training in evolution for biology teachers, taking into account the suggested goals of Sickel and Friedrichsen (2013), aids in significantly improving the three variables studied: teachers' understanding of NOS and their understanding and acceptance of evolution. However, we can also conclude that the relationship among these variables appears to be complex, going beyond a simple positive correlation. More studies are necessary to determine whether teaching and evolution together in fact produces a synergistic effect (Ha et al., 2015).

One of the limitations identified in this study presents itself at the level of the study design and methodology. On one hand, there was no measurement of other important variables, such as the participants' religious beliefs or their intention to teach evolution. On the other hand, due to the absence of a control group, it is difficult to determine the causality between the teachers' understanding of NOS in the posttest and teachers' understanding and acceptance of evolution. Although the transformation of empirical data into knowledge and of knowledge into acceptance is a reasonable model for explaining the relationship between NOS and understanding of evolution (Bayer & Luberda,

Table 3. Spearman correlation coefficient between the variables studied ($N = 31$).

Variables	NOS-post	NOS-gain	ACORN-post	ACORN-gain	MATE-post	MATE-gain
NOS-post	1	0.347	**0.401***	0.031	**0.494***	−0.187
NOS-gain	–	–	**0.430***	0.265	**0.384***	−0.042
ACORN-post	–	–	–	0.501	**0.505***	−0.171
ACORN-gain	–	–	–	–	0.334	0.195

*$p < .05$.
**$p < .01$.

2016), further work using causal study designs is necessary to determine whether understanding NOS is in fact a sufficient and necessary requirement to better understand and accept evolution (Ha et al., 2015). Our recent study concerning this issue in students tells us that NOS could be a necessary requirement for improving the acceptance but not the understanding of the mechanism of natural selection (Cofré et al., 2017).

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