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To cite this article: Cristina Cobo, Ana-María Abril & Marta Romero-Ariza (2022) Effectiveness of a contextualised and integrated approach to improving and retaining preservice teachers' views of the nature of science, *International Journal of Science Education*, 44:18, 2783-2803, DOI: [10.1080/09500693.2022.2151326](https://doi.org/10.1080/09500693.2022.2151326)

To link to this article: <https://doi.org/10.1080/09500693.2022.2151326>



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Published online: 15 Dec 2022.



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Effectiveness of a contextualised and integrated approach to improving and retaining preservice teachers' views of the nature of science

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ABSTRACT

Teachers are key players in supporting the understanding of epistemological and social aspects affecting the development and validation of scientific knowledge, but they often hold inappropriate views of the Nature of Science (NOS), therefore hindering this understanding as an essential part of students' scientific literacy. To tackle this challenge from the initial teacher education level, an innovative inquiry-based intervention contextualised in the scientific controversy of spontaneous generation has been developed and evaluated by involving pre-service teachers. Results from a pretest/posttest-control group design showed improvements in the understanding of the epistemological and sociological aspects after the intervention. The effect size detected in the experimental group versus the control group was retained and even enhanced five-and-a-half months after its completion. These results are especially relevant to respond to experts' claims about the need for further studies to understand the issues related to retention following explicit instructions about NOS. Additionally, qualitative data provided an enriched picture of the participants' understanding of the NOS, unveiling the complexities of the different issues involved and suggesting the need to combine quantitative and qualitative studies. Finally, implications for teacher educators and educational researchers are presented along with directions for future work in the field.

ARTICLE HISTORY

Received 1 September 2021
Accepted 21 November 2022

KEYWORDS

Initial teacher education;
nature of science; retention

Introduction

Current trends in science education highlight the importance of teaching about the Nature of Science (NOS) in formal education (Lederman et al., 2013; OECD, 2019). However, historical debates about the conceptualisation and teaching of NOS have hindered its appropriate integration into classroom practice. Beyond these tensions, many authors support the inclusion of general and specific aspects of NOS in various subject matters, at different levels of compulsory education (Hodson & Wong, 2017; Kampourakis, 2016).

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To achieve this aim, several educational proposals advocate promoting a better teachers' understanding of NOS (Abd-El-Khalick, 2013; Aragón-Méndez et al., 2019; Mesci, 2020; Mulvey & Bell, 2017; Vázquez-Alonso et al., 2013). However, few studies explore how views of NOS change over time, especially among preservice teachers.

According to the aforementioned concerns, this work evaluates the effect of an innovative intervention on preservice teachers' understanding of diverse issues of NOS in the short and medium-term to provide evidence-based research on successful didactic proposals for enhancing and retaining views of NOS in initial teacher education.

NOS in science education

On a general level, the NOS refers to the characteristics and development of scientific knowledge. This term comes from the Science-Technology-Society movement that emerged in the 1970s to unify a wide range of issues about science and technology and its bidirectional relations with society, as well as to guide the educational treatment of those ideas in science education for scientific literacy (Vesterinen et al., 2014). During the last decade, this approach resulted in the consensus view of NOS (Lederman et al., 2013), which turned into its prevailing conceptualisation. The consensus view mostly emphasises epistemological features about scientific knowledge (empirical, tentative, and subjective), processes (observations, inferences) and products of science (theories, laws). Besides the cognitive foundation of science, this approach also highlights certain social features, represented by the role of scientists' creativity and the socio-cultural context.

Nevertheless, some authors have recently claimed the social aspects of NOS as delving into the multiple human aspects involved in the construction, validation and dissemination of scientific knowledge, such as the professional relationships between scientists and political and economic powers (Aragón-Méndez et al., 2019; Hodson & Wong, 2017; Vázquez-Alonso et al., 2013). This approach can offer a holistic view of science to address a more critical understanding of scientific enterprise and participation in daily life and socio-scientific issues (Allchin, 2011; Herman et al., 2019; Hodson & Wong, 2017).

Effective teaching of NOS also requires reflection on key issues about science through didactic scenarios that are purposely designed to elicit them (Abd-El-Khalick, 2013; Kruse et al., 2020). In fact, several educational interventions have proven their effectiveness in promoting appropriate views of NOS. Nevertheless, generic instructions based on non content specific activities seem to represent a major obstacle in the transfer of views of NOS to real situations than content-imbedded ones (Allchin et al., 2014; Cofré et al., 2019). In this regard, Clough (2018) advocated deeper learning of NOS through a continuous and highly contextualised scaffolding.

The history of science (Aragón-Méndez et al., 2019; McComas, 2011) and inquiry-based learning (Ozgelen et al., 2013; Yacoubian & BouJaoude, 2010) are some of the most-used methods to teach NOS within a contextualised approach. To complement the affordances and overcome the deficiencies of a unique approach, Allchin et al. (2014) suggested integrating different pedagogies to promote the understanding of NOS. More precisely, Abd-El-Khalick (2013) proposed combining the history of science and inquiry-based learning to address the development and validation of

scientific knowledge. These suggestions can address a broader scope of science that emphasises its sociological features in authentic contexts.

NOS and teacher professional development

Initial teacher education is a key step in supporting sustainable changes in the quality of formal science education that is aimed towards scientific literacy (Clough, 2018; Lederman et al., 2013; Mesci, 2020). This purpose emphasises the learning of NOS in the earliest stages of teacher training, as explained below.

First, many studies reveal that teachers exhibit inappropriate conceptions about NOS, which may affect the quality and objectives of science education. Second, some works advocate that teachers' views of NOS influence their teaching orientations (Abd-El-Khalick, 2013; Wahbeh & Abd-El-Khalick, 2014). Specifically, Abd-El-Khalick (2013) discussed the relevance of teaching scientific knowledge foundation (teaching *about* the NOS) to enable the design and development of educational scenarios embedded in current views of science (teaching *with* NOS). Therefore, if teachers understand the empirical, changing, subjective and social features of NOS, they can promote a student-focused approach, based on the construction of knowledge, reasoning and discussion.

Third, promoting adequate views of NOS among teachers also helps transfer that knowledge to the science classroom. Nevertheless, solely an improved view of NOS is not sufficient to enable its teaching, a prerequisite knowledge about science is essential to feel confident and enhance the teaching of NOS in practice (Abd-El-Khalick, 2013). In fact, several authors claim that both preservice teacher development programmes and in-service ones (Wahbeh & Abd-El-Khalick, 2014) should allow for the improvement of NOS views to properly address key issues of the NOS through science teaching.

In order to properly address these concerns, we need meaningful and contextualised pedagogical approaches embedded in the way scientific knowledge is constructed to improve preservice teachers' views of NOS, so they can later promote informed views of science among their future students.

Regarding the epistemological dimension of NOS, very often teachers exhibit a static, absolutist and objective view of science (Mesci & Schwartz, 2017; Wahbeh & Abd-El-Khalick, 2014). On this matter, Akerson et al. (2006) commonly found the ingenuous idea that if scientists had more data, they would reach the same interpretations. Nevertheless, teachers usually sustain informed views about the empirical basis of science (Cofré et al., 2019). With respect to the sociological issues, Mesci (2020) highlighted a large number of preservice teachers who conceived scientific knowledge as independent from the socio-cultural context. Other studies also reported misunderstandings about scientists as always being unbiased and open-minded (Herman & Clough, 2016). Against this, the role of imagination and creativity is one of the most well-understood aspects of NOS (Cofré et al., 2019), although some studies revealed an insufficient consideration of them in scientific processes (Herman & Clough, 2016; Mesci, 2020).

Other studies have evidenced future teachers' difficulties to express their thoughts about NOS and some inconsistencies when arguing about the generation of scientific knowledge (Aragón-Méndez et al., 2019; Mesci, 2020). In this sense, Aragón-Méndez et al. (2019) highlighted obstacles to integrating epistemological and sociological

factors, predominantly the latter, to justify the delay of new research acceptance, which alludes to a compartmentalised knowledge of NOS.

Furthermore, an important aspect to evaluate the effectiveness of a particular educational intervention aimed to improve NOS views is to track the maintenance of these views. Retention is a crucial aspect of learning since it reflects the extent to which individuals are able to remember and apply the understanding acquired. However, measuring retention is a challenging issue since it requires a highly demanding research design. In fact, few studies focus on the evolution of teachers' improved conceptions about NOS and show discrepant results among them.

Akerson et al. (2006) stated that along the semester, preservice teachers reverted to their initial conceptions five months after an explicit and reflective NOS integration in science lessons. In contrast, later successful interventions included several contextualised activities, providing a meaningful context to illustrate and understand particular aspects of the NOS. In that regard, Mesci's (2020) study showed the retention of future teachers' informed views a year after the development of a PCK-based NOS instruction. Most of the studies address in-service teacher training and in this case, the pedagogical NOS course developed by Wahbeh and Abd-El-Khalick (2014) succeeded in maintaining NOS views five months after its completion. The courses of NOS based-activities developed by Mulvey and Bell (2017) and Herman and Clough (2016) also proved the retention of improved NOS in-service teachers' views for longer periods, 10 months and two to five years post interventions, respectively.

Based on the previous considerations, this work intends to analyse the effectiveness of an integrated and contextualised Teaching and Learning Sequence (TLS) to improve and sustain preservice teachers' views of the NOS over time.

The term integrated refers to two different characteristics of the TLS. The first one addresses the understanding of both epistemological and sociological dimensions of the NOS. The second characteristic alludes to the different pedagogical approaches combined in the TLS, which have proven to be effective in promoting adequate views of NOS (the use of history of science, inquiry activities and explicit reflection).

Hence, the following research questions are posed:

- (1) What is the (short- and medium-term) impact of an integrative and contextualised TLS on preservice teachers' understanding of sociological and epistemological issues related to NOS?
- (2) How do preservice teachers envision NOS because of the TLS?

Research methodology

The methodology used is framed in a quasi-experimental pretest/posttest-control group design, extended with a delayed posttest and complemented by qualitative data from participants exhibiting different profiles (Creswell, 2012).

Sample and context description

The experimental and control groups were natural groups of 100 undergraduate students enrolled in a compulsory science education subject of the Elementary Education Degree. Though students taking part in the experimentation and control groups were invited to

fill the pre- and post-questionnaires, the return response was lower than expected since the fulfilment was voluntary. Responses in the experimental group included 57 student questionnaires (24 men and 33 women) in the pretest/posttest/delayed posttest, while 30 students (12 men and 18 women) fulfilled the questionnaire in the control group in the pretest/posttest and 35 students posttest (15 men and 20 women) in the delayed. Five students in the control group did not complete either the pretest or the posttest. Therefore, we are left to assume they possessed similar NOS views to those of their peers before and immediately after the intervention (Herman & Clough, 2016). The average age was 21 years in both groups.

Thus, the experimental and control groups took part in the same initial teacher training, although the approach used to teach the contents was different. In that regard, the TLS was implemented only in the experimental group, within the context of the teaching hours devoted to practical activities of the subject, while the control group received traditional training. That is, the experimental group experienced an inquiry-based learning approach designed to enhance explicit and reflective learning of NOS in authentic contexts, embedded in historical scenarios about the construction of scientific knowledge. This approach was characterised by a significant educator's guidance through small and whole-group questioning and discussion (Lazonder & Harmsen, 2016). Meanwhile, teaching in the control group focused on didactic activities aimed to improve the understanding of scientific contents, with no specific reflection on NOS during the inquiry activities or historical treatment of scientific contents.

The control group was included in the study to overcome the influence of multiple formal and informal educational factors that may influence assessment outcomes (Morris, 2008). Learning takes place in naturalistic contexts, thus, it is essential to study the progress of a control group, which did not receive the experimental educational treatment (the TLS) to better ensure a proper reading of results when analysing improvements over time in the experimental group.

The review of the syllabus of the previous subjects studied in the university degree by preservice teachers revealed that neither of the two groups had ever received any formal explicit training about NOS.

Intervention

The TLS titled 'Inquiring about the origin of living beings' involved inquiry activities embedded in the historical scientific controversy of spontaneous generation to teach about NOS (Cobo et al., 2019, 2020). It was developed across six face-to-face hours (three sessions of two hours/week) and structured in four phases (Table 1).

Preservice teachers carried out several inquiry activities in the first three phases of the intervention (A, B, C), according to the approach described by Pedaste et al. (2015). Initially, they were challenged with daily observations leading to the view of spontaneous generation through a historical tale of science. Subsequently, they were asked to design their own experiments to refute the spontaneous generation of mould in rotten oranges (reconstruct the history of science). Afterwards, they were introduced to the analysis of historical episodes about the scientific controversy through the questioning of the quality of experiments as well as evidence and inferences of scientists of the time (discovering the history of science). The whole process was scaffolded through

Table 1. Phases of TLS.

Phases	Didactical purpose	Tasks	Inquiry activities	Methodology: organisation
A – Generate cognitive conflict	Elicit pre-existing ideas about the origin of living beings and NOS.	Read a short text about Aristotle and reflect: Why do you think he defended the origin of fishes from the mud of the lake? Could you formulate alternative hypotheses? Did he use scientific methods? Why was his explanation accepted?	Question and explore the challenging inquiry context.	Brainstorming: small groups (4–5 participants) and whole-group discussion.
B – Reconstruct the history of science	Promote active participation in the reconstruction of the historical controversy.	Design and experiment about the research question: How would you prove that mould does not appear in oranges spontaneously?	Generate hypothesis, design experiments, observe, collect evidences, assess and interpret data.	Guided inquiry in the laboratory: small groups.
	Reflect on the issues of NOS addressed along with the inquiry task.	Answer reflective questions, e.g.: Did you explain the observations in the same way? Do scientists explain observations in the same way? Did you change your explanation? Do scientists change theirs? If we considered whole class results, would our conclusions be more reliable?	Communicate, discuss and reason results and conclusions, and evaluate the reliability of research.	Explicit reflection: small groups and whole-group discussion.
C – Discover the history of science	Reflect on factors that influence scientific knowledge construction.	Analysis of statements and experiments made by relevant scientists involved in the controversy in the 17th–19th centuries, through specific NOS questions. See the example in the Appendix	Evaluate hypothesis, experimental designs, evidences, inferences and the communication of research.	Guided inquiry on the history of science: small groups.
D – Consolidate	Reflect on contents.	Answer open-ended questions (Table 4)	-	Explicit reflection: individual.

guiding questions to promote a conscious reflection on issues of NOS (Kruse et al., 2020). This way, we pretended to explicitly discuss the characteristics of experimental research and scientific knowledge as well as the socio-historical aspects that inevitably influence scientists' work (see examples in Table 1 and the Appendix). Finally, each student answered some open-ended questions about issues of NOS addressed throughout the TLS (see Table 4).

Instruments

The instrument used to assess the effectiveness of the TLS in improving preservice teachers' views of NOS over time was a standardised paper-and-pencil questionnaire of 10 items (Table 2), extracted from the Spanish and adapted version of Views on Science, Technology and Society (VOSTS) (Vázquez-Alonso et al., 2013).

Table 4. Open-ended questionnaire used to assess views of NOS at the end of the TLS.

Reflective questions	Abbreviation	Dimension of NOS
1. Spontaneous generation theory was described to get evidence about the origin of living beings. However, over time, it was replaced by the biogenesis theory. Do you think all scientific theories are tentative?	Q1_tentativeness	Epistemology
2. What is the role of mistakes in science?	Q2_mistakes	Epistemology
3. Do you think that all scientists had the same motivation when inquiring about spontaneous generation?	Q3_motivations	Sociology
4. If you think about your inquiry in the laboratory or about scientists like Van Helmont, Needham or Pasteur, what role do imagination and creativity play in scientific work?	Q4_standards	Sociology
5. What aspects do you think influence the acceptance of a new scientific theory?	Q5_theories	Sociology
6. In the spontaneous generation controversy, how did scientists compete to defend their beliefs?	Q6_comptetitiveness	Sociology
7. Why do you think this controversy persisted for so long?	Q7_persistence	Epistemology and sociology

Each item introduced an issue of NOS followed by sentences that expressed different positions on the issue (appropriate, plausible or naïve) (see examples in Table 3), previously assigned by a panel of expert judges according to the current knowledge of specialists in NOS (Vázquez-Alonso et al., 2013).

Preservice teachers assessed their degree of agreement with each sentence on a nine-point scale. The instrument also offered the possibility to indicate: 'I do not know enough about the issue' or 'I do not understand the sentence'. Those direct scores were transformed into standardised and normalised indices $[-1$ to $+1]$. The average of the indices of each sentence was turned into the index of the item. Values closer to the maximum index ($+1$) indicated more appropriate views of NOS, and vice-versa (Vázquez-Alonso et al., 2013).

Additionally, each preservice teacher in the experimental group wrote their understanding of NOS at the end of the instruction, in the form of a reflective open-ended questionnaire (Table 4). This task intended to obtain more detailed information about

Table 2. Items of VOSTS used as a research instrument.

Dimension	Issue	Item	Short description
Epistemology	Definition	10113	The general process of science consists of obtaining empirical evidence and testing hypothesis.
	Theory-laden	90111	Scientists' observations, interpretations and research are guided by their beliefs, knowledge, expectations or theoretical commitments.
	Tentativeness	90411	Scientific knowledge (facts, theories, laws) are reliable and durable but never absolute.
	Mistakes	90651	Mistakes are intrinsic to scientific practice and occasionally, they have new discoveries or advances.
Sociology	Society	20821	Scientific construction is influenced by the historical and social context.
	Motivations	60111	The main reason for doing science depends on particular qualities of scientists (e.g. fame, money or curiosity).
	Standards	60211	Scientists are concerned with imagination, creativity, objectivity, open-minded and impartiality.
	Disagreements	70211	Disagreements occur due to scientific and moral reasons (e.g. absence of irrefutable facts and personal benefits).
	Theories	70221	The logic structure of a theory and scientists' feelings influence the acceptance of new theories.
	Competitiveness	70411	Scientists compete to obtain economic aids that fund their research, which may cause conflicts of interests.

Table 3. Example of items used to assess the progress in preservice teachers' views of NOS.**Epistemology: 90111. Scientific observations made by competent scientists will differ if they believe in different theories.**

- | | |
|---|----------|
| A. Yes, because scientists will do different experiments and see different things. | a |
| B. Yes, because scientists will think differently and this will alter their observations. | a |
| C. Scientific observations will not differ much even if scientists believe different theories. If they are really competent their observations will be similar. | i |
| D. No, because observations are as accurate as possible. This is how science has advanced. | i |
| E. No, observations are exactly what we see and nothing else; they are facts. | i |

Sociology: 60111. Most scientists are motivated to try hard at their work. The MAIN reason for their personal motivation to do science is to:

- | | |
|---|----------|
| A. Receive recognition, otherwise their work would not be accepted. | a |
| B. Earn money, because society pressures scientists to strive for financial rewards | i |
| C. Acquire a little fame, money and power, because scientists are like the rest of people. | p |
| D. Satisfy their curiosity about the natural world, because they like to learn more and solve the mysteries of the physical and biological universe. | p |
| E. Solve curious problems for personal knowledge AND discover new ideas or invent things for the benefit of society (for example, medical remedies, solutions to pollution, etc.). All this together represents the main motivation of most scientists. | p |
| F. Selflessly invent and discover new things for science and technology. | i |
| G. Discover new ideas or invent things for the benefit of society (for example, medical remedies, solutions to pollution, etc.) | i |
| H. It is not possible to generalise because the main motivation of scientists varies from one to another. | a |

Note: a = appropriate; p = plausible; i = ingenuous.

the construction of NOS views, help them to consolidate the new knowledge acquired and make them restructure and express their thoughts.

Most questions specifically addressed a dimension of NOS, except for Q7. This last, more general question embedded epistemological and sociological aspects of the construction of scientific knowledge to delve into preservice teachers' thoughts and abilities to describe science as a whole (Kruse et al., 2020).

Data collection and analyses

Quantitative data collection (obtained from the 10-item VOSTS questionnaire) took place three times: (1) a month-and-a-half before the intervention (pretest), (2) a month-and-a-half after the intervention (posttest) and (3) five-and-a-half months after the intervention (delayed posttest). Qualitative data (obtained from the open-ended questionnaire) were collected in the last phase of the TLS (Table 1), thus before the posttest.

The effectiveness of the TLS was assessed through the independent-samples t-test and the effect size, the latter to overcome the over-reliance on significance tests as a means of supporting the hypothesis (Cohen et al., 2012; Creswell, 2012). The effect size represents a powerful tool to interpret the magnitude of the effectiveness of interventions, and it is widely recommended in pretest/posttest research studies with a control group (Morris, 2008). In this work, the effect size was applied from two perspectives: (i) to assess the intragroup progress in the experimental and control groups individually; (ii) to assess the global effectiveness of the TLS, considering the progress of both groups (Cobo et al., 2020). An effect size greater than zero indicates positive progress in learning, and an absolute value of 0.30 or greater indicates relevant progress (Cobo et al., 2020).

Furthermore, qualitative data were collected from participants exhibiting different initial profiles and reactions towards the intervention. These data provide a deeper understanding of preservice teachers' views of NOS immediately after the intervention and, as a

consequence, more evidence about the effectiveness of the TLS (Cohen et al., 2012). Following the purposeful sampling procedure (Creswell, 2012), four students were selected according to the progress revealed in their pretest/posttest 10-item VOSTS questionnaire. Overall, two of these four students exhibited high VOSTS posttest indices in most items and the other two, poor ones. A triangulation was made (Cohen et al., 2012) between the VOSTS indices and students' written reflections; the data were reported using pseudonyms.

Results

First, the progress in the NOS views of the experimental group is presented and compared to that of the control group through pretest and posttest indices. Second, the retention of the knowledge acquired four months after the posttest in the experimental and control groups is described. Third, the global effectiveness of the intervention is analysed. Finally, qualitative data provided a better understanding of the effects of the intervention, which allowed identifying the strengths and weaknesses of the TLS.

Pretest/posttest comparisons in the experimental and control groups

Figure 1 shows the short-term evolution of NOS views in the control and the experimental groups.

Overall, preservice teachers in the control and experimental groups exhibited similar pre-existing views of NOS, with no significant differences in any item (independent-samples *T*-test). Both groups exhibited slight positive indices for mainly all items but negative in relation to the motivations (Figure 1(a,b)). The general posttest profile of the control group exhibited a decreased scoring so that only three items in the social dimension

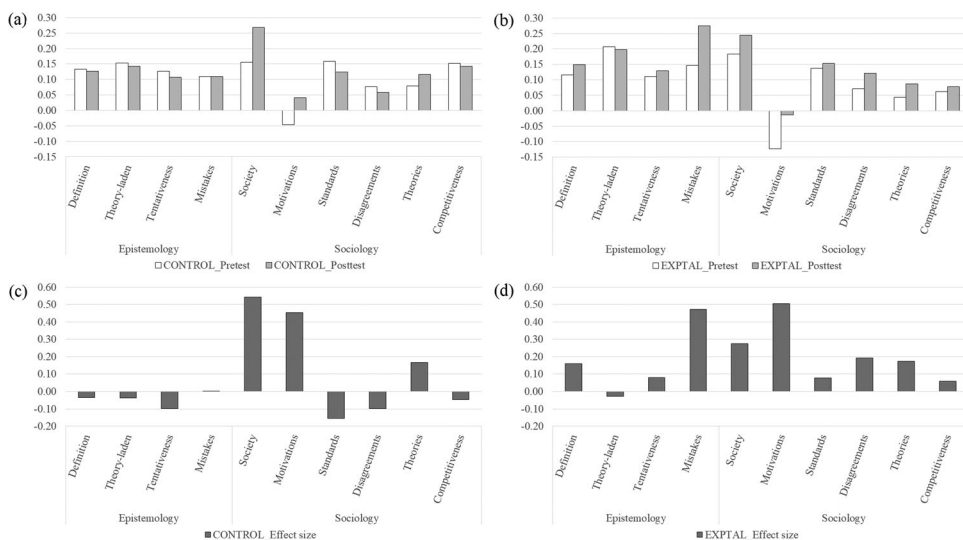


Figure 1. Short-term evolution of NOS views. Above: Pretest and posttest average indices in the control (a) and experimental (b) groups. Below: Effect size in the control (c) and experimental (d) groups.

improved their initial indices. Two of them reached a relevant effect size (≥ 0.30): motivations and society (Figure 1(c)), although significant differences were only observed for the latter (Table 5). However, there was an increase in nine items in the posttest of the experimental group (Figure 1(d)), with two significant and relevant improvements (Table 5).

Analysis of retention in the experimental and control groups

To grasp the future retention of improved NOS views at a later time, and to provide evidence-based research about the medium-term impact of the TLS, the control and experimental groups were tracked for a new assessment (delayed posttest), four months after the posttest assessment, that is five-and-a-half months after the end of the intervention.

Figure 2 shows the general retention of the experimental group's improved NOS views, even progress in the delayed posttest (Figure 2(b)) versus the control group's ones (Figure 2(a)). In this latter, NOS views declined in six items, even for the two items that had exhibited the biggest improvements in the pretest/posttest (society and motivations), which decreased with a remarkable effect size (≤ -0.30) (Figure 2(c)). This is an interesting result that suggests the need to question the views of NOS promoted through traditional instruction to avoid the risk of supporting naïve views when the science teacher education is not well aligned with the current understanding of NOS.

In contrast, the experimental group experienced noteworthy progress towards even more informed views of NOS (Figure 2(d)). In this case, two items stood out among the others, with significant differences between the posttest and the delayed posttest indices (Table 6). This remarkable result reveals a progressive and robust acquisition of key ideas about NOS in the experimental group. This outcome is further significant when compared to the control group's profile over time.

Analysis of the intervention's effectiveness

Till now, we have presented the effect size for the experimental and control groups based on the pre/post means of NOS views indices. These results were analysed in parallel to assess what happened during the formal instruction stage, either traditional or innovative. If instead of calculating the effect size within a particular group (intragroup), we use Morris (2008) approach for a pretest/posttest two-group research design, the resulting value will offer a clearer view of the effect of the innovative intervention under study.

Table 5. Items in the ten-item VOSTS questionnaire associated with significant improvements in the pretest/posttest.

	Pretest			Posttest			Effect size	P
	N	M	SD	N	M	SD		
Items								
Experimental group								
Mistakes	54	0.147	0.312	57	0.274	0.221	0.47	0.015*
Motivations	57	−0.124	0.215	57	−0.013	0.223	0.51	0.008**
Control group								
Society	30	0.156	0.194	30	0.268	0.216	0.54	0.041*

Note: N = sample size; M = mean; SD = standard deviation.

* $p < 0.05$.

** $p < 0.01$.

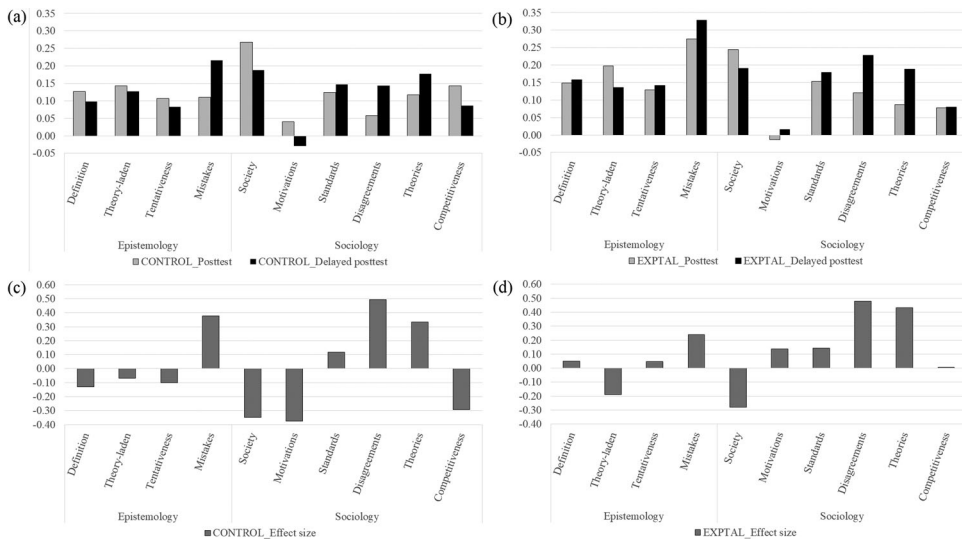


Figure 2. Retention of NOS views. Above: Posttest and delayed posttest average indices in the control (a) and experimental groups (b). Below: Effect size in the control (c) and experimental (d) groups.

In Morris' approach, the effect size is based on the difference between the posttest-pretest score mean in the experimental group minus the corresponding difference in the control group, divided by the pooled standard deviation (Cobo et al., 2020; Morris, 2008).

Concerning Figure 3, eight out of 10 items exhibited improvements in the short term (Effect size_Prestest/Posttest), and the highest effect size was detected in the mistakes issue (0.46). Regarding medium-term effectiveness (Effect size_Prestest/Delayed Posttest), improvements were also observed in eight items. In this case, it is worth mentioning that the effect size in seven items was higher than the one detected in the short term, and five of them exhibited relevant magnitudes for both epistemological and sociological dimensions of NOS: definition (0.39), tentativeness (0.31), motivations (0.62), disagreements (0.40) and competitiveness (0.32).

An in-depth view from qualitative analysis

Participants exhibiting different profiles and reactions towards the innovative intervention were purposefully selected to develop a better understanding of the potential influence of the innovative TLS, as well as to identify those aspects of the intervention

Table 6. Items in the ten-item VOSTS questionnaire associated with significant improvements in the posttest/delayed posttest.

	Posttest			Delayed posttest			Effect size	<i>p</i>
	<i>N</i>	<i>M</i>	SD	<i>N</i>	<i>M</i>	SD		
Items								
Experimental group								
Disagreements	57	0.121	0.244	56	0.229	0.203	0.48	0.012*
Theories	57	0.087	0.247	57	0.189	0.223	0.43	0.023*

Note: N = sample size; M = mean; SD = standard deviation.

* $p < 0.05$.

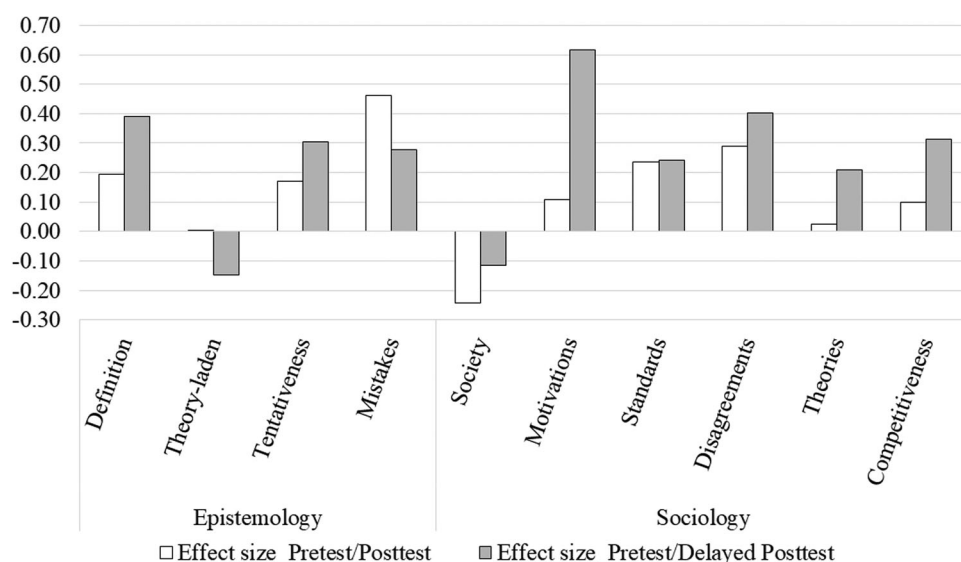


Figure 3. Short- and medium-term effect size of the intervention based on Morris (2008).

that should be revised to increase their effectiveness. To this end, four students were purposefully selected according to their pretest/posttest indices. Thus, Paul and Nancy represent students who experienced a general improvement (GI) in most NOS issues, therefore exhibiting more informed views about the epistemological and sociological dimensions after the intervention. In contrast, Christine and Francine represent students who either experienced a general decline (GD) or maintained naïve views on most NOS issues (Figure 4).

The analysis of the written responses to the open-ended questions (Table 4), along with the corresponding pretest/posttest VOSTS indices, provided a deeper insight into how students with different profiles of NOS views understood particular issues about science foundation.

Regarding epistemological issues, students who generally improved their views of NOS provided evidence of how they perceived crucial factors related to the stability of scientific knowledge (Q1_tentativeness). Paul responded, 'I don't think any theory is final. One theory is replaced by another one when the latter provides better responses to a particular question or better describes what really happens'. Nevertheless, students with lower VOSTS indices in the posttest exhibited more naïve views. In this case, Christine attributed theories the same status as the hypothesis: 'Yes, I think scientific theories may be tentative in the sense they are just hypotheses, and they can never be 100% approved'. Meanwhile, Francine expressed a vague thought: 'Yes, research outcomes may change over time due to the arrival of new scientists who want to continue checking those research outcomes'.

However, the four students expressed an informed view of the inherent presence of mistakes in science (Q2_mistakes), though with slight differences. For example, Paul (GI) stated, 'Mistakes are necessary to reject hypotheses and they can help us to orient our research in a different direction. A mistake should never be understood as a delay, but rather, as an approach to what we are investigating'; while Christine (GD) responded,

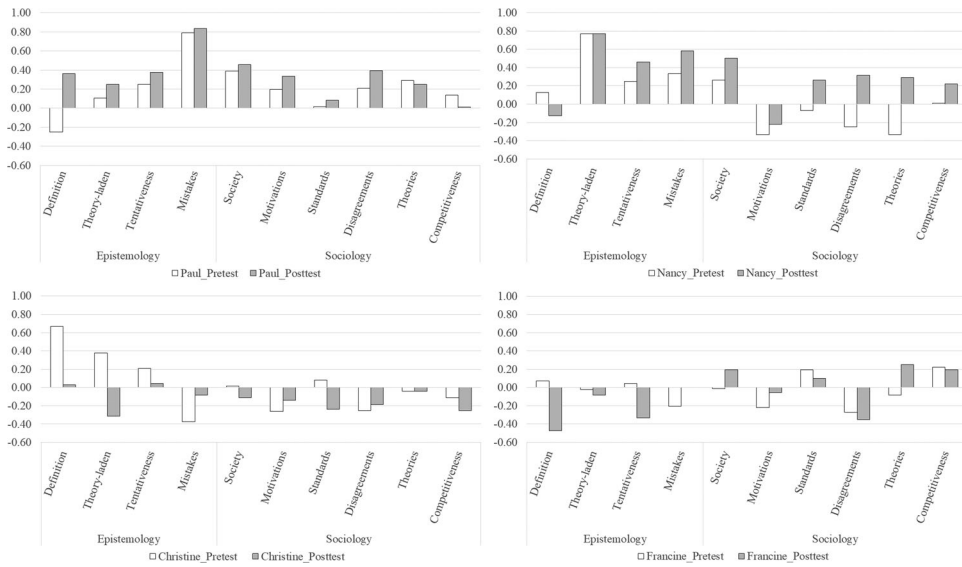


Figure 4. Pretest and posttest indices of students that showed a general improvement (above) or decline (below) in the 10n-item VOSTS questionnaire after the intervention.

‘I think mistakes have a very important role in science since an error can delay science, but at the same time, it can inspire other scientists’. However, Christine’s VOSTS index did not show this more informed view on the balanced role of mistakes.

Students’ responses to Q3_motivations, Q4_standards, Q5_theories and Q6_competitiveness, revealed interesting details about how they understood particular social issues of NOS.

On this matter, the four students properly alluded to the importance of imagination and creativity in science, though not all explained it with the same depth. Paul and Nancy (GI) specified its importance in different scientific processes (e.g. Paul: ‘Sometimes, imagination can be useful to interpret data from different points of view or to carry out tests in one way or another’). In contrast, their peers revealed the poorest responses (e.g. Francine: ‘They have a very important role to go beyond research’). However, for this issue (standards), VOSTS posttest indices did not show noteworthy differences between both groups, although only Paul and Nancy slightly improved their initial understandings.

Nevertheless, most of the students inaccurately believed that all scientists shared the same motivations to investigate, and all of them thought scientific competitiveness does not go beyond experimental demonstrations. For instance, Christine (GD) stated, ‘I think every scientist wanted to demonstrate the origin of living beings in the best way and this was the main objective’. When referring to competitiveness, Paul (GI) responded, ‘Scientists compete with each other through different experiments that refute the hypotheses put forward by others and repeating the experiments to check their reliability’. Of the four different profiles selected, Nancy (GI) was the only one who properly stated that ‘motivation is a very subjective aspect that varies at different times’. In addition, she only expressed that ‘scientists competed to prove their theories through research, but influenced by their knowledge and believes’, thus interrelating epistemological (theory-laden) and sociological (competitiveness) issues of NOS. She

also obtained the highest posttest index for the theory-laden issue. According to competitiveness, the VOSTS assessment did not show general progress, with mainly low posttest indices that were in line with the students' written explanations.

With respect to the aspects that influence the acceptance of new theories, Nancy (GI) highlighted subjective ones ('personal interests, motivations, prior knowledge and attitudes'). On the contrary, Paul (GI) alluded to 'the explanatory capacity of the theory, its coherence and limitations', and Christine (GD) to 'checking the objectives and hypothesis proposed, asking new questions, collecting information and reviewing the experiment'. Despite this, later the students referred to objective aspects – Paul explicitly referred to the consistency of theories, whereas Christine revealed a less accurate view based on the need to verify several scientific processes. Only Francine (GD) poorly referred to both objective and subjective reasons: 'The theory must be testable, truthful and aligned with the scientist viewpoint'. In this case, Nancy and Francine's VOSTS indices showed an improvement in the posttest and achieved a similar positive outcome to Paul's index. These results are consistent with their written reflections, which showed transitional but incomplete views of this issue of NOS, or more substantiated ones. In addition, Christine exhibited the poorest reflection and the smallest and most negative posttest index.

Finally, students who generally improved their views of NOS after the intervention, referred to social factors to explain the perpetuation of spontaneous generation of controversy (Q7_persistence). On the one hand, Paul highlighted the historical context: 'Scientists' mindset was difficult to change and tradition had great importance beyond all the evidence against the spontaneous generation. In addition, religion played a very important role'. On the other hand, Nancy addressed the lack of agreement among the scientific community: 'There was no definitive conclusion that everyone could agree on, each one wanted to show what they thought without considering others' opinions or discoveries'. In contrast, Christine (GD) implied greater importance to objective factors: 'Any other theory was proven against spontaneous generation', as well as Francine (GD), although the latter seemed to allude to the divergence of the scientists' mindset: 'The research of every school of thought was not proven'. Nevertheless, none of the four students specifically considered both epistemological and sociological factors. In a consistent way, Paul and Nancy's VOSTS indices were higher in relation to the origin of scientific controversies, considering the influence of society and scientists' disagreements, despite the fact that they did not even articulate several sociological aspects in their explanations.

Referring to the epistemological issue about the empiric nature of science, the aforementioned students' responses highlighted the need to obtain evidence to test hypotheses, though only Paul's (GI) VOSTS posttest improved in this regard (definition).

In the following, we discuss data in more detail to draw some conclusions and implications for future research on the topic and for effective teaching about NOS.

Discussion

The results shown in this work provide evidence to discuss the extent to which the designing of the intervention was effective in improving preservice teachers' views of NOS.

In relation to the first research question that referred to the impact of the TLS on pre-service teachers' views of NOS, pretest/posttest indices showed the experimental group improved their understandings in nine out of 10 issues related to both epistemological and sociological issues. However, the control group, subjected to a science content instruction without explicit reflection on NOS and the history of science, experienced an improvement in only three issues. These results support the effectiveness of the intervention and respond to one of the major claims that advocate a whole vision of NOS instruction (Allchin, 2011; Hodson & Wong, 2017).

According to the evolution of the acquired views of NOS five-and-a-half months after the intervention (delayed posttest), the experimental group retained the more informed views in eight out of 10 issues and also further improved them in seven issues. On the contrary, the control group reverted to less knowledgeable views in six out of ten issues. This was especially interesting because two of these issues corresponded to those that had experienced the greatest improvement in the pretest/posttest analysis. Therefore, these results support a specific educational treatment of NOS throughout the teaching-learning process of scientific contents to enhance and sustain the adequate understanding about science (Abd-El-Khalick, 2013; Clough, 2018).

Our study challenged the one carried out by Akerson et al. (2006), which suggested that one intervention was not enough to make NOS learning last five months after instruction among preservice teachers. Several authors have recommended using multiple activities contextualised in varied meaningful situations to improve teachers' views of NOS (Abd-El-Khalick, 2013; Clough, 2018; Lederman et al., 2013; Mesci, 2020; Mulvey & Bell, 2017; Wahbeh & Abd-El-Khalick, 2014). In line with these recommendations, our study shows how a particular sequence of activities helped pre-service teachers to meaningfully grasp and retain key ideas about the NOS. They developed inquiry-based experiences to prove the spontaneous generation theory and reviewed key historical episodes to discuss the evolution of scientific knowledge. Therefore, we present an integrated and contextualised approach to teach NOS (Allchin et al., 2014) and provide an alternative use of the history of science (McComas, 2011). Our approach engaged pre-service teachers in the 'reconstruction' of key science ideas through experimentation and in the reflection of alternative ideas coming from different sources (their own experiments and the history of science). Additionally, and in line with previous works (Aragón-Méndez et al., 2019), the analysis of different arguments and schools of thought helped them to appreciate the dialogic nature of science. Particularly, the analysis of the scientific controversy of spontaneous generation supported explicit reflection about the multiple aspects influencing science development and the impact of scientists' personal traits and views within a particular socio-cultural context.

Furthermore, our results extend the evidence provided by previous studies that have shown teachers' progressions regarding NOS conceptions over time, but have not compared them against a control group (Herman & Clough, 2016; Mesci, 2020; Mulvey & Bell, 2017; Wahbeh & Abd-El-Khalick, 2014). In this case, the effect size measure considering a pretest/posttest-control group design proved the effectiveness of the TLS in increasing and retaining the understanding of most sociological and epistemological issues of NOS addressed in this study, which suggests a noteworthy medium-term impact of the TLS on preservice teachers' NOS views.

Nevertheless, the theory-laden item was the most resistant epistemological issue to change, as Cofré et al. (2019) have already suggested in their study. Related to the tentativeness of scientific knowledge, it is worth mentioning that some previous studies have suggested a regression to less informed views over time (Mesci, 2020; Wahbeh & Abd-El-Khalick, 2014). However, our results support those obtained by Mulvey and Bell (2017) and Herman and Clough (2016), which evidenced a retention and even improvement of those informed views. With respect to the sociological dimensions of NOS, the social embeddedness of science was a challenging idea, which again reinforced previous studies (Cofré et al., 2019; Mesci & Schwartz, 2017). In this regard, even though the experimental group improved their views at short-term, they reverted to less sophisticated ones five-and-a-half months after the intervention, in line with Mesci (2020), Mulvey and Bell (2017) and Wahbeh and Abd-El-Khalick (2014). Our study reveals that the control group also exhibited this profile, which evidences the influence of uncontrolled factors in preservice teachers' views of NOS, such as motivational and socio-cultural ones, although further research is needed to delve into this matter (Mesci & Schwartz, 2017).

In relation to the second research question, the written reflections from the qualitative analysis provided a richer picture of how preservice teachers in the experimental group envisioned particular issues of NOS at the end of the TLS, to deepen the analysis of its effectiveness. Therefore, not only did we identify informed views about epistemological and sociological issues of NOS but also some aspects that require refinement.

According to the epistemological dimension, they properly considered mistakes as part of science. The TLS helped them to conceptualise mistakes as opportunities to improve research, but this overly positive view also allowed them to avoid recognising that, in a certain way, mistakes entail a delay in the development of science. Furthermore, all of them alluded to the empirical basis of science and advocated the tentativeness of scientific knowledge. In this last case, a misconception related to the epistemological status of hypotheses and theories was found (Cofré et al., 2019), when justifying the changing nature of science.

Related to the sociological dimension, the four students recognised the relevance of creativity and imagination in the construction of scientific knowledge, although not all of them properly explained the role of these standards, as Herman and Clough (2016) and Mesci (2020) noted. There was also a tendency to consider the subjectivity in science when reflecting about the acceptance of new theories and the persistence of the spontaneous generation of controversy, though we found the social aspects more difficult to integrate into reflections, in contrast to Aragón-Méndez et al. (2019).

Moreover, students who experienced a general progress in the pretest/posttest VOSTS assessment tended to provide more precise and better-articulated responses when discussing the controversy about the origin of living beings. These results are relevant due to the contribution of the TLS to a more functional knowledge of science (Allchin, 2011), and for considering that in-depth understanding of scientific ideas requires the understanding of NOS (Herman et al., 2019). However, these students were unable to articulate both objective and subjective aspects of the development of scientific knowledge, such as the logical structure of theories along with scientists' personal interests, as well as integrate sociological and epistemological issues to explain the persistence of controversy. Aragón-Méndez et al. (2019) had also highlighted this

concern. In this respect, Ozgelen et al. (2013) showed some limited connections between both dimensions of NOS in preservice teachers' reflections, following an explicit and reflective course based on practical inquiry-based experiences to target specific NOS aspects. However, they recognised the need for findings to solve 'whether instruction that specifically addresses the relationship between the various NOS aspects may be more effective in helping students develop such connections, and indeed to develop much deeper connections than those explicated by our participants.' (Ozgelen et al., 2013, p. 923).

Nevertheless, views about motivations and competitiveness were primarily the most naïve. In fact, only one student recognised that the motivation to research the origin of living beings might depend on personal scientists' aims, and no students referred to social factors involved in the scientists' competitiveness. This was surprising because the TLS showed some personal traits of scientists and the support offered by other scientists and institutions to maintain their reputation. Again, this evidence highlights the unwavering conception of objectivity in the scientific enterprise.

Regarding the aforementioned aspects, the qualitative results revealed some misconceptions of NOS, despite the quite positive evolution of the quantitative VOSTS assessment. Moreover, some inconsistencies were found when contrasting VOSTS indices and preservice teachers' open reflections. In this, some authors reported how teachers had difficulties conveying particular aspects of NOS openly, even when they had agreed with the opposite before (Aragón-Méndez et al., 2019). It is possible that participants also found it difficult to articulate their ideas when responding to the open-ended questionnaire, even though the wide range of options offered for the NOS issues in the VOSTS may have assisted them to express them in the posttest (Vázquez-Alonso et al., 2013). Likewise, it is worth mentioning that the robust structure of the VOSTS may have also entailed a high cognitive engagement in testing students' views of NOS by allowing different, appropriate, plausible and ingenuous views being offered to score (Table 3), thus revealing more inaccurate views of NOS than those expressed in some open-ended questions. These results highlight the complexity of NOS learning and assessment processes, as well as underscores the importance of mixed-methods to provide a richer perspective of the development of NOS views.

Despite the abovementioned, the outcomes suggest that short interventions based on an explicit, reflective, contextualised and integrated instructional approaches offer a meaningful educational scenario to adequately support preservice teachers' views of NOS and their maintenance over time. The TLS implementation attempted to provide a high scaffolding in the understanding of NOS through hands-on activities and the analysis of daily life and historical cases (Abd-El-Khalick, 2013; Allchin et al., 2014; Clough, 2018). This logical sequence also aimed to engage preservice teachers in the social discussion about NOS in a cognitive and emotional way (Lederman et al., 2013; Ozgelen et al., 2013). Therefore, this approach for teaching NOS suggests being an effective way for incorporating feasible and effective didactic proposals in the initial teacher training stages.

In conclusion, following a pretest/posttest/delayed posttest-control group research design, this work provides rich and solid evidence-based research about the effectiveness of a TLS to promote and maintain over time the informed views of the NOS in preservice teachers. In addition, qualitative data allow triangulation and a better understanding of

the effects of the intervention on participants. These results are relevant due to the following facts:

- (1) Understanding how science develops and validates that knowledge is essential to educate critical and well-informed citizens who can evaluate current scientific activities and advances
- (2) Research shows that teachers often exhibit a deficient understanding of NOS, which is a serious obstacle in their key role as promoters of a scientifically literate society
- (3) The present work addresses the primary claims of the specialised literature, providing evidence of an effective short-time intervention for initial teacher education, based on integrated pedagogical approaches to enhance the understanding of epistemological and sociological issues of NOS. This evidence is supported by a quantitative and qualitative research design and the study of a control group's views of NOS.

In the near future, we would like to replicate this work in different contexts to improve the understanding of those NOS issues that have been proven to be more resistant to change, and continue working on teacher education for the teaching of NOS as the fundamental leverage of a more scientifically literate society.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work is supported by the Spanish Ministry of Economy and Competitiveness and the European Regional Development Fund [grant number EDU2015-64642-R] and the University of Jaen [grant number R5/04/2017].

Institutional review board statement

Data were collected after obtaining formal approval from the Ethical Committee for Social Sciences and Humanities of the UNIVERSITY OF JAÉN (protocol code MAY.18/10.TES), which was approved on 18th June 2018).

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Appendix. Example of a narrative and activities extracted from the historical case of spontaneous generation given to preservice teachers in the phase C of the TLS.

In the seventeenth century, Belgian chemist, physiologist and physician Jean Baptiste van Helmont (1579–1644) noted the necessary ingredients to the origin of certain living beings as a recipe book in *Ortus Medicinae* (1648), as follows:

Creatures like lice, ticks, fleas, and worms are our miserable guests and neighbours, but they are born from our guts and excrements. If we place sweat-filled underwear with wheat in a wide-mouthed container, after 21 days, the smell changes and the ferment from the underwear penetrates the wheat husks and changes the wheat into mice. But what is even more remarkable is that mice of both sexes are formed and can be crossed with mice born in a normal way ... but what is truly incredible is that mice emerged from wheat and sweaty underwear are not tiny, misshapen or defective, but perfect adults.

1. Reflect on the content and meaning of each of the following sentences to decide if it is an observation or an inference:

- a. Creatures like lice, ticks, fleas and worms are born from our guts and excrements
 - b. The ferment from the underwear penetrates the wheat husks and changes the wheat into mice
 - c. After 21 days, mice appear between the sweaty underwear and wheat
 - d. Emergent mice are perfect adults of both sexes
2. How do you think an observation differs from an inference?
3. Why do you think van Helmont made those inferences?
4. If you were citizens of the seventeenth century and had to take a stance for or against spontaneous generation, what aspects would you like to delve into with this experiment?