The Influence of Real-Context Scientific Activities on Preservice Elementary Teachers’ Thinking and Practice of Nature of Science and Scientific Inquiry

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Abstract
Understanding how and why science works is a major goal of science education. The aim of this article is to analyze the influence of a research experience in real science contexts, in the thinking and practice of preservice elementary teachers regarding inquiry and nature of science teaching. An in-depth case study which highlights the affordances and shortcomings of the participants’ immersion in real science contexts and in seminars and its impact on participants’ thoughts and practices of nature of science and inquiry will be presented. Interviews, observations, diaries, and videotaped seminars were used for data collection. Our findings suggest that the research experience, as well as moments of reflection, contributed to enhance the relevance of an inquiry-based teaching and teaching about NOS in the participants’ discourse. However, the implementation of these classroom practices was limited and seemingly prevented due to various constraints, namely the initial teacher training, participants’ lack of teaching experience, and those associated with elementary students and the curriculum.

1 Introduction

Students’ understanding of how and why science works, the understanding of nature of science (NOS), is a major goal of science education (McComas & Clough, 2020; Nouri et al., 2021; Olson, 2018). The COVID-19 pandemic has highlighted how fragile this knowledge is in the overall population and the work educators and science communicators have ahead of them (Allchin, 2021; Maia et al., 2021). Beyond these long-standing
science education goals, that is nature of science (NOS) and scientific inquiry (SI), different reform documents reinforce these aspects as science education outcomes (Lederman, 2019).

However, several studies reveal a significant difference between curriculum perspectives and teacher practices (Banilower et al., 2013; Capps & Crawford, 2013a, 2013b; Capps et al., 2016). Therefore, it is necessary that training institutions look for new strategies that effectively support (future) teachers to implement NOS and inquiry teaching (Roth & Lavoie, 2001). Of the many training strategies aimed at improving NOS and SI in preservice teachers, the research experiences (RE) where learners worked with scientists on authentic scientific research have been suggested as a new possible approach.

Changes regarding future teachers’ thinking about NOS and SI have been reported as a consequence of RE (Anderson & Moeed, 2017; Enderle et al., 2014; Pop et al., 2010; Schwartz et al., 2013). However, mixed results were obtained with regard to the changes in teacher practices (Capps et al., 2012; Krim et al., 2019; Sadler et al., 2010). While difficulties associated with the transfer of the RE to the classroom context were reported by some studies (Brown & Melear, 2007; Schwartz et al., 2013), others reported changes (Blanchard & Sampson, 2018; Hughes et al., 2012). Nevertheless, in some of these investigations, direct analysis of teacher practices was not considered, and the assessment is based on self-reported data through interviews or based on information sent by the participants (videos or lessons plans). In addition, in most studies, the teaching practices observations do not provide information about NOS teaching.

It is also important to note that there are differences between the RE programs investigated in these studies. The differences encompass elements such as the immersion period, the support provided regarding the transference into the classroom, and the nature of the research developed (Enderle et al., 2014; Hughes et al., 2012).

According to Sadler et al. (2010), understanding the impact of particular and singular features of these experiences on promoting or inhibiting the learning of (future) teachers will allow for an adequate conceptualization of these programs. However, current research is limited in terms of identifying the features of the RE that play the biggest role in the learning process. According to Southerland et al. (2016), these “experiences have been treated as a ‘black box’ by simply examining the influence that participation in research has on a selected outcome” (p. 3). Thus, despite the growing literature on this subject, there are still several issues that require further investigation.

The present study aims to explore the impact of research experiences in real science contexts, offered in the Live Science program (LSP), in preservice elementary teachers’ conceptions and practice related to inquiry and NOS teaching. The questions guiding this research are as follows: (1) How have preservice elementary teachers’ views of science teaching changed as a result of their participation in the LSP?; (2) How does the LSP affect preservice elementary teachers’ actions within the classroom? Analyzing the development arising from the singularities of this program will clarify which components of the program contribute to changes in teacher conceptions and practices. These findings can then be used to guide the design of future research experiences.

This study presents three main features that are not usually pursued in the relevant literature of the field (Capps et al., 2012; Krim et al., 2019; Sadler et al., 2010). Firstly, it includes preservice elementary teachers, a population that is not normally involved in these studies. Secondly, it examines not only the value of the RE in promoting inquiry-based instruction in the classroom, but also in NOS teaching. Finally, the effect of research experiences on participants practice was assessed through classroom observations along several sessions and interviews.
2 Inquiry and NOS

Not only is NOS present in many curricular documents and the subject of a wide range of empirical and theoretical research, it is also a desired learning outcome in all school years. According to Lederman (2007), it is possible to identify a set of items which hold a sufficient level of consensus to permit NOS aspects to be narrowed down to tentativeness; creativity; subjectivity (theory-laden); functions and relations of theory and laws; social and cultural embeddedness; being empirically based; and a necessity to distinguish between observations and inferences.

While it can be conceded that the “Lederman Seven” list is an assortment of diverse items that come from distinctive insights into the scientific enterprise and scientific knowledge, its pedagogical value in introducing the NOS in K-12 classrooms has been well documented. Thus, opting for the Lederman approach has not been arbitrary, but anchored in its extensive use in preservice teacher (PST) knowledge of NOS along with existing assessment instruments (Kampourakis, 2016).

The promotion of more informed conceptions of NOS has been achieved with assorted approaches. These can be categorized as implicit/explicit or contextualized/non-contextualized. The implicit approach believes that developing a more informed picture about NOS is a natural consequence of the participant’s involvement in different activities, whereas the explicit approach presupposes that this development should be intentional, through the planning of moments that promote reflection about science (Abd-El-Khalick & Akerson, 2009). In non-contextualized teaching, NOS corresponds to the first aspect of teaching and uses discussion activities that are not directly related to scientific concepts. In contrast, in the contextualized approach, NOS is integrated into certain scientific content or processes (Clough, 2006).

Although some success has been achieved in developing informed conceptions of NOS through the implementation of explicit and reflective teaching, some evidence suggests that the transfer of this understanding to the classroom is complex and diverse factors mediate its translation (Lederman, 2007).

The separation between the concept of scientific inquiry and NOS is an essential clarification. While the former is related to the work that is performed during the development of scientific knowledge, the latter refers to the epistemological underpinnings of the activities of science and the characteristics of the resulting knowledge (Lederman et al., 2014).

Despite inquiry learning being well-established, inquiry teaching is more problematic, as is confirmed by Anderson (2007), “the only real test of the presence of inquiry teaching is whether or not students are engaged in inquiry learning” (p. 823). In inquiry teaching, the aim is to help students process information and communicate with groups, coach student actions, facilitate student thinking, and model the learning process. According to the National Research Council (2000), students participate in inquiry when they engage in scientifically oriented questions; give priority to evidence; formulate evidence-based explanations; evaluate the strength of their explanations; and communicate and justify explanations.

Although inquiry teaching is a highly valued approach in official documents and in the science education community, several studies indicate that it is not widely adopted by teachers (Capps & Crawford, 2013a; Capps et al., 2016). Different aspects seem to influence the (non)adoption of this teaching approach. For example, external factors like lack of resources and time, lack of collaboration, and inconsistency with curricula are perceived as constraints impeding the use of inquiry (Baroudi & Rodjan Helder, 2021; DiBiase &
McDonald, 2015; Fitzgerald et al., 2019). However, research findings suggest that in particular, it is internal factors such as knowledge, beliefs, and attitudes that affect whether teachers implement inquiry-based teaching (Crawford, 2007; Wallace & Kang, 2004). It is therefore essential to address these internal factors, to understand how they relate to practices and how they evolve in order to foster inquiry teaching in classrooms.

### 3 Research Experiences (RE) for (Future) Teachers

The participation in RE is a training model inspired in apprenticeships and claims that the “processes of learning and understanding are socially and culturally constituted, and that what is to be learned is integrally implicated in the forms in which it is appropriated” (Lave, 1997, pp. 18,19). Therefore, it is possible to conclude that knowledge should be presented in authentic contexts and learning requires social interaction and collaboration (Lave & Wenger, 1991). Several authors establish a close relationship between the research experiences (RE) in real science contexts (RSC) and the concept of participation, introduced by Lave and Wenger (1991). This association is particularly true when we want individuals to achieve the role of full participants in a community. Nevertheless, the association is different when referring to RE of preservice teachers (PST) in scientific communities. It is at this point that the concept of trajectory becomes useful to analyze this difference (Wenger, 1998). In inbound trajectories, “newcomers are joining the community with the prospect of becoming full participants in its practice” (Wenger, 1998, p. 154), while peripheral trajectories never contribute to a full participation. The trajectories of the future teachers in RSC fall mostly in the latter category as it is primarily intended that future teachers have the opportunity to observe, collaborate, and reflect on authentic scientific practices in real contexts. Programs that enable (future) teachers to participate in RSC assume that this experience, even based on peripheral trajectories, can have profound impacts on the conceptions and practices of these professionals. Although a reasonable assumption, it requires empirical evidence that supports it. For this reason, it is essential to analyze studies which investigate the effects of these programs on (future) teachers’ learning. It is also important to note that these programs sometimes differ.

For example, some initiatives provide an additional component where teachers can interact with their peers involved in the program to discuss pedagogical strategies. Some programs take place in the summer; others are part of a curricular unit offered in the initial teacher training. There are also other characteristics that have varied such as the immersion period, the level of education that the teachers teach, as well as the nature of the research developed, and the support provided by the scientists. Regarding the latter, a simplified investigation is sometimes conducted, since the teachers work on a special project, which although slightly related to the scientists’ research is simplified to enable pedagogical use; in other situations, the research is “real”, since the teachers collaborate in some aspects of the scientists’ research (Hughes et al., 2012). In other cases, teachers observe the research team without undertaking a project or participating directly in the research. Given this diversity, it is necessary to describe the specificities and singularities of each program to relate the effects to the lived processes.

Difficulties regarding the transference of the RE to the classroom context have been reported by some studies. Three future secondary teachers enrolled in a RE were studied by Brown and Melear (2007). Despite having developed scientific skills and content knowledge, the transfer of the experience to their classrooms was notably limited.
Participants listed time constraints, curricular specifications, and final examinations as the main reasons for their difficulty in implementing inquiry methodology in their lessons. The work developed by Schwartz, Northcutt, Mesci, and Stapleton (2013) suggests the enrolment in a RE led teachers to a more student-centered teaching. However, an inquiry style was difficult to implement, and priority was not given to NOS or nature of scientific inquiry in participants’ lesson plans, mainly due to constraints such as time management, misconceptions, resources, and the content.

Nevertheless, changes regarding teachers’ thinking and practices have been reported as a consequence of RE. Results presented by Westerlund et al. (2002) suggest that a RE “can be successful at promoting teacher change towards more inquiry teaching” (p. 79). It is claimed that this success is a consequence of the teachers’ increase in content knowledge, enthusiasm for teaching science, and opportunities to participate in a scientific dialogue with scientists.

Pop et al. (2010) ascertain that after a RE, teachers reported a higher number of lessons in which students were required to apply science to real-life situations and more confidence in teaching science as well as feeling more motivated about attending other similar professional development programs. Dixon and Wilke’s research (2007) suggests that both the quantity of science taught and the confidence with which it was done significantly increased after two teachers participated in a RE. This in turn generated the discussion of the importance of scientific thinking and improved motivation in their students. The importance of communication in science, the planning of moments that foster communication among students, and the discussion of characteristics of scientific careers were all recognized by one teacher in the study.

Mentoring styles and teachers’ level of participation in RE were recently identified by Hughes et al. (2012) as important aspects that modulate teachers’ abilities to transmit these experiences to their students.

The study conducted by Enderle et al. (2014) demonstrated that participants’ conceptions about teaching and learning have become closer to those advocated in educational reforms, after participation in a RE. However, the changes were more evident among the participants who attended a pedagogy-focused program (the investigations were authentic for the participants, but not to the scientific community; while also including planning research activities to be implemented in classrooms) compared to the changes in the teachers who attended a research-focused program (the investigations were authentic to the scientific community; inquiry teaching was contemplated only during a 2-h session). However, this research did not explore the features of the program that have contributed to the developments identified. In particular, it did not explore the characteristics of the different RSC. In a follow-up study, Southerland et al. (2016) analyze the data on 106 teachers in both the research-focused and pedagogy-focused programs and found that personally relevant research experiences were more powerful than necessarily “authentic” science experiences. The authors emphasize that there may be multiple pathways to influencing changes in teachers’ practices.

4 Methodology

4.1 Live Science Program

The LSP was guided by different approaches. It first adopted an authentic and contextualized approach (Lave & Wenger, 1991). The authenticity was conferred by immersing participants
in a real science context (RSC) for 3 weeks. Then the LSP adopted an explicit and reflective approach to help PST to question their beliefs and make sense of their experiences. There was also a participatory, dialogical, and collaborative approach. Given these last two approaches, the program also included seven seminars. The goal of the first seminar was to provide a description of the RE, four seminars were to foster a collaborative and shared reflection regarding NOS, and the last two were for the discussion of science teaching and learning, and how the RE could be translated to the classroom. For the last two seminars, situations experienced in real science contexts with the potential to trigger discussions regarding NOS and inquiry teaching were selected for discussion. Films documenting inquiry activities with elementary students were also watched.

4.2 Science Contexts and Participants

Four PSTs, Helena, João, Leonor, and Carla (pseudonyms), participated voluntarily in this study. All the PSTs have a 3-year bachelor degree (a generalist 3-year bachelor’s degree that does not confer professional qualifications) and were enrolled in the last year of a 2-year master program aimed at elementary teacher training in a Portuguese School of Education.

The distribution of the participants was based on their preference: Helena and João collaborated with Frederico, a geology researcher, who was performing analogue and numerical modelling experiments to study the tectonic interference between geological faults; Leonor and Carla collaborated with the researcher, Diana, in a project about the development of new anti-malarial drugs through an in vivo approach. The two scientists were selected based on their previous experience in terms of collaborative work with students and teachers.

In Valente et al. (2018), the features of the RE offered in the LSP were described. Although evidence indicated that all PST were legitimate peripheral participants, differences were observed between the two RSC. The geology group was characterized as a richer experience due to the frequency and nature of support provided and having more diverse and richer group relationships.

4.3 Data Sources and Analysis

Data collection was conducted in two main stages: (i) before, during, and after the LSP; (ii) during 9 weeks of the internship in the scope of a supervised teaching practice course. The chronology of data collection can be seen in Fig. 1.

4.3.1 Stage 1

Before the LSP, semi-structured interviews were conducted (I1) (Appendix I) in order to explore the participants’ views about science teaching and learning. Each participant also read seven critical incidents—situations or episodes which prompt (future) teachers to decide on a course of action (Nott & Wellington, 1996) (CI1) and explain what they would do or say in that situation. CI help document and portray teachers’ NOS knowledge and pedagogical content knowledge for NOS. Since no appropriate CI for (pre)service elementary teachers or adapted to the Portuguese curricular context were found, CI were developed (Appendix II).

During the apprenticeship, participants created an electronic laboratory notebook (LN) where their research activities and reflections about the RE were written. The RSC were observed, and informal conversations were had that permitted an insight into what PST
Fig. 1 Instruments used and respective codes
were thinking regarding the experience. These conversations were documented in field-notes (FN). The LN and FN were important to prepare the reflective seminars, which were videotaped and transcribed. Due to the research issue, for this study, the data from the LN, FN, and the first three seminars were not used. Only data from the two seminars on the discussion of ideas about science teaching and learning will be used.

After the program, final interviews (I2) were conducted to gain insight into the participants’ views about the LSP and to obtain information regarding their perceived learning outcomes (Appendix III). Final critical incidents (CI2) were presented, and participants were once more asked to state their perceived actions and words in the imaginary situations.

The analysis of the data from the above sources was achieved with the grounded theory approach (Corbin & Strauss, 2008). Through open coding, recurring ideas regarding teacher views of science teaching were identified. Then axial coding was used to group and label these ideas into categories. In the final stage, all categories were placed into the following dimensions: inquiry teaching; NOS teaching; perceived learning outcomes; constraints associated with the adoption of an inquiry; and NOS teaching.

### 4.3.2 Stage 2

After the LSP, and in the scope of the supervised teaching practice course, the participants participated in a 9-week internship in the context of the lower primary (years 1–4). The PSTs provided their science lesson plans in advance.

João taught only two science activities during the internship and due to time constraints was only observed in one. Given this, it has been decided not to include this observation in the present study. Nevertheless, it was possible to observe at least four lessons for the other participants.

Upon completion of the supervised teaching practice, an interview (I3) was conducted to obtain an overall assessment of the implementation of science activities in the classroom and explore some opinions held by the participants using data collected over observations (Appendix IV).

The data analysis of the lesson plans, lesson observations, and I3 was a combination of data-driven and theory-driven strategies. For the implementation of an inquiry teaching, the analysis was based on the categorization established in the National Science Education Standards (National Research Council, 2000) which defines five essential features of a classroom inquiry. According to the aforementioned, the essential features of classroom inquiry are learner engagement with scientifically orientated questions; priority to evidence which allows for the development and evaluation of explanations that address scientifically orientated questions; the formulation of explanations from evidence to address scientifically oriented questions; the evaluation of the learners’ explanations in light of alternative explanations, particularly those reflecting scientific understanding; and the communication and justification of learners’ proposed explanations. During the analysis, an attempt was made to discover evidence of the existence of these features and determine the level of student autonomy.

With regard to NOS teaching, first, the learning objectives present in the lesson plans were analyzed, making it possible to determine the participants’ intentions regarding the NOS. Subsequently, situations that illustrate teaching about NOS either implicitly or explicitly were explored.
5 Results

5.1 Participants’ Views of Science Teaching

5.1.1 Inquiry Teaching

At the beginning, all participants criticized the traditional teaching approach: “Not a lecture where the teacher says, opening the book on page x and now memorize” (Helena, I1); “The least appropriate strategy is to stay in the classroom and just talk” (João, I1); “Lecture and individual work are the least appropriate strategies” (Carla, I1). The need to take into account students’ interests and students’ previous knowledge was a cross-cutting aspect in all participants. Additionally, the importance of making science more interesting and fun for the students was mentioned.

Practical activities were believed to be the best strategy in science lessons due to the aforementioned ideas. By analyzing the nature of these activities, it appears that they were essentially sensory. Group work and large group discussions were also strategies valued by the participants. These aspects suggest that even before the LSP, the participants considered student involvement to be important, gave emphasis to practical activities, and were concerned about making science fun. However, there was no explicit or implicit reference to an inquiry-based teaching because despite appreciating data collection, it was not referred to as evidence to develop explanations.

At the end of the program, some of the characteristics of a good science lesson that participants had originally mentioned remained apparent in the participants’ discourse. Nevertheless, differences were detected. On one hand, the importance of fun was no longer mentioned as an end in itself, but rather as a necessary condition for learning. On the other hand, participants began to explicitly refer to several key aspects of an inquiry-based teaching. Moreover, the goal of making the activities more authentic or closer to the ones practiced by the scientists was mentioned. However, this was not the same for all the participants.

Both in the I2 and in the CI2, Helena mobilized almost all essential features of an inquiry-based teaching. The students’ involvement in questions with a scientific orientation was very clear: “Teaching through problems in opposition to contents, because I think that’s how you learn science… starting from questions” (Helena, I2). Furthermore, Helena’s discourse reflected a greater concern with the involvement of the students in data collection and treatment in order to solve the questions, the importance of sharing and exchange ideas between students, and the development of argumentation among students.

João reinforced the importance of diagnosing students’ misconceptions. She also mentioned the importance of implementing dialogic discursive practices in the classroom. Moreover, data collection became regarded as a useful tool to build answers to questions and hypotheses created by the students or by the teacher. There was also a visible decrease in lecture time and an increase in time devoted to the collection and treatment of data in the final critical incidents.

Leonor also revealed a stronger inclination towards inquiry. She is of the opinion that in a good science lesson, students should be the ones responsible for the research: “to participate in all aspects, in the collection, observation, analysis [of data]” (Leonor, I2). She began giving a greater emphasis to students’ voices through a greater openness of the activities and stimulating a greater interaction among students. Greater student involvement in the collection and data treatment was also clear.
Carla was the participant with less visible changes. She continued to value practical activities of a sensory nature. The description of a good science lesson also revealed a strong concern in motivating students via the careful selection of topics and attractive resources. Analysis of Carla’s data revealed low student involvement as well as the adoption of strategies being strongly grounded in oral presentation by the teacher.

5.1.2 NOS Teaching

Initially, teaching NOS was quite undervalued by the participants. For example, when asked about the skills that they believe should be developed in science lessons, no reference was made to the development of skills in this area. Above all, participants valued “doing” rather than “thinking about it.”

The analysis of the initial critical incidents corroborated this lack of visibility. For example, when João was confronted with the critical incident about the class fish that had died during the Easter holiday, she only said: “since we could not perform an autopsy on the fish, we do not have the resources to find out which of these three options is more accurate, so I would say that none of the three options is wrong” (João, C1). Only the tentative nature of scientific knowledge and the scientists’ image were dealt with in a more explicit way.

Throughout the program, but particularly in the final two seminars, participant discourse began to reveal an increase in the value of the importance of teaching about the NOS. However, participants revealed some difficulty indicating the most appropriate strategies to address the NOS. For Leonor, the adoption of a more inquiry approach would be possible because for her “just the fact that we are doing experiences, practical activities, we are connecting kids to what the scientist does, isn’t it?” (Seminar). In other words, she believed that involving students in scientific processes while “doing” science would increase their motivation to learn about science. Helena and João had different views as they considered it important to explicitly explain the NOS features. For João, the History of Science could be an important tool if accompanied with explicit guidance from the teacher. For all the participants, questioning constituted a fundamental strategy in teaching about NOS.

In the I2, when challenged to indicate the skills they thought should be valued in science, participants made explicit references to learning about the NOS. For Leonor, science classes should include “a narrative for students to realize what happened before reaching a certain conclusion, that there were people who investigated, which sometimes is not mentioned” (Leonor, I2). Helena also valued different NOS features, such as “that science is not leakproof, that we can problematize, we can question … realize that today it is one thing, and tomorrow it can be something else” (Helena, I2). For Carla, the tentative nature of scientific knowledge should also be discussed with students, for example, “knowing that science is always changing, that now it is this way, but in the future it can be another way” (Carla, I2).

For all participants, the number of episodes dedicated to teaching NOS increased in the final critical incidents. For example, João made efforts to explicitly explain to students’ aspects of NOS, such as what a hypothesis is and its validity:

First of all, what I would say is that they are hypotheses, that there is no wrong hypothesis or a right hypothesis, there are hypotheses. I think this would be my first reinforcement (...) Then we could observe, research, compare (...) and then accept that (...), but then we have the question of, we didn’t go looking for other hypotheses, is it really that one, despite all the evidence pointing to it? (João, IC2)
These also revealed that not all aspects of the NOS were equally invoked by the participants: the tentative nature of scientific knowledge, the difference between observation and inference, and the scientist’s image were the most predominant NOS features. However, there were differences in the approach adopted. Both Helena and João used mainly an explicit and reflective approach, whereas in Leonor and Carla’s case, the lecture approach was adopted the most:

the goal would be for them to understand that science is ever evolving, that it is not a static thing, and they [students] try to understand why this happens, and they would come to different conclusions (…) it’s not just about knowing that science evolves, but understanding why that happens, finding some way for them to understand it, and why it happens (Helena, CI2)

I would say that everything is evolving… that things change, that the knowledge that people have is changing, and this makes science [also] changing and these concepts, these ideas, also change (...) because we have new resources, new technologies, and as society changes, the mentality also changes (Carla, CI2)

Nevertheless, participants revealed some difficulties in translating their understanding to specific activities.

5.1.3 Perceived Learning Outcomes

According to the participants, the LSP allowed the development of learning at different levels. Due to immersion in the RSC, participants reported an increase of substantive knowledge and, above all, process skills. They also reported learning in regard to NOS, in particular developing a new image of scientists and the work they do. Both the RE and the seminars contributed to an increase of interest and enthusiasm in science, particularly for Helena, Leonor, and João. For Carla and Leonor, the program and in particular the seminars were equally useful in promoting reflection and critical thinking. Educational-pedagogical learning was mentioned explicitly only by Helena and João. Regarding the influence of the LSP on future teaching practices, two participants—Helena and Leonor—reported a greater enthusiasm for teaching science.

Making science teaching more authentic was an objective expressed by all participants. According to Leonor: “I want to put them to work like they [the scientists] also work” (Leonor, I2). To achieve this goal, participants showed willingness to introduce new strategies during the science lessons. The students’ involvement in different scientific processes such as observation and data collection and a greater concern for student interest and prior knowledge were aspects mentioned by all the participants. For João and Carla, the program deepened the desire to reduce the lecture component during their science lessons. The desire to increase the time devoted to communication among students was also mentioned by Helena and Leonor.

For Helena, the program also helped to increase her confidence in science teaching, in particular, the adoption of a more open inquiry approach. She started to consider the possibility of developing more open, less structured activities. According to Helena “contact with science and what science really is, made me lose my fear … it made me curious and perhaps gave me the courage to risk a little more” (Helena, I2). Realizing that “even with a scientist with lots of experience, things go wrong” (Helena, I2) was important in aiding Helena in understanding that the research process is not linear but infused with problems and errors. As such, the “tendency to despair when an activity … goes wrong” (Helena,
I2), a fear that she harbored before her involvement in the program, was now devalued. Also, after the LSP, the development of more open activities, which address more than one conclusion, was seen as a possibility: “today I think it’s okay not to reach just one conclusion” (Helena, CI2).

5.1.4 Constraints Associated with the Adoption of an Inquiry and NOS Teaching

According to the participants, the implementation of an inquiry and NOS teaching was difficult, particularly during the internships. These difficulties were a consequence of four different sources: initial teacher training, intrinsic ones, and those associated with elementary students and the curriculum.

The difficulties associated with initial teacher training were related with the mentor teachers, the supervisors, and the organization of the internships. The influence of the mentor teachers was complex and multifactorial. All participants agreed that these teachers did not adopt innovative practices regarding science education (“in the internship I never saw a practical activity carried out,” Carla, Seminar), devoted little time to science and awarded it a secondary role compared to other subjects. The gap between the mentor teacher practices and future teacher beliefs seemed to cause dilemmas and tensions over the role they should adopt during the supervised teaching practice.

The role played by the supervisor also constituted a constraint. For João, the fact that these teachers did not value the NOS offered an explanation as to why they did not approach these aspects. However, it was the supervisors’ role as an assessor that had greater prominence in this category, in other words, the supervisors’ negative evaluation of lesson plans that were not accomplished.

Regarding intrinsic constraints, participants mentioned the lack of teaching experience. Due to this and the evaluation of the internship, different concerns associated with the adoption of less traditional approaches emerged, such as the fear of failing to manage the class or being unable to respond to students’ questions. João and Leonor also mentioned constraints associated with the students’ cognitive development. For them, certain aspects of the NOS were difficult to understand and, as such, did not suit first and second year students’ cognitive capacity. Although the participants’ opinions diverged, issues regarding students’ behavior and lack of interest were also mentioned. According to Leonor, the adoption of an inquiry approach with an open nature could be especially problematic in classes with motivation and behavior problems. Comments like “I think all [boys and girls] would love [inquiry activities]” (João, Seminar) or that “curiosity is intrinsic to all children in the world” (Helena, Seminar) showed that Leonor’s vision was not one that was shared.

Finally, the constraints associated with the Portuguese elementary curriculum were mostly mentioned by João. On the one hand, she stressed the absence of explicit references to NOS in official documents. According to João, “and if it is not properly written, so explicit, it is not content …, like the water cycle, such a visible content” (João, Seminar). On the other hand, she referred to the nature of the syllabus. In her opinion, “the syllabus in the four first years doesn’t connect with this” (João, Seminar).

Due to the constraints associated with being trainees, Leonor and Carla (more so than the others) established a clear boundary between the type of teaching they believed to be possible to implement in the context of supervised teaching practice, and what they would later adopt: “but when we have our own class, it will be different” (Leonor, Seminar).
However, Helena seemed to favor the adoption of an inquiry and NOS teaching even during the initial training.

5.2 Participants’ Teaching Practices

5.2.1 Inquiry-Based Approach

Student involvement in a question with a scientific orientation was observed sporadically in Leonor and Carla lessons (Table 1). This is quite interesting because both participants identify this aspect as being an essential characteristic of the scientific process. When questioned about the reason why they normally stated the purpose of the activity and not the question to be answered, Leonor indicated that: “for me, when guiding the activity, it is easier to have an objective, but for the students maybe it is better to have a question. But I didn’t even think about this when planning” (Leonor, I3). Only Helena adopted this aspect in a systematic way in her teaching practice and made great efforts to help students formulate their own questions. For example, the science project was triggered by the question—“What animals can we find in the playground?” During the project, several questions arose, some proposed by Helena and others formulated by the students. The questions raised by the students resulted either from an explicit request from Helena or doubts that arose from students’ observations.

Prioritizing evidence was the most visible aspect in all participants. In Leonor and Carla’s case, the determination of the aspects that should be taken into account as evidence was often done without students’ participation: “we are going to measure the quantity of water” (Carla, FN); “we are going to see whether the magnets attract each other or not and whether they attract different objects” (Leonor, FN). The needs to control students’ behavior and to accomplish the plans were the main reasons for the adoption of a more teacher-centered approach by these two participants. (“I was more concerned with accomplishing what I had planned” (Carla, I3); “I felt the need to guide them, I felt the need to tell them, you have to this, and this, because I was being observed” (Leonor, I3)).

In Helena’s lessons, the determination of the aspects that should be taken into account as evidence was done mainly by the students during the planning activities. For example, to answer the question—What animals can we find in the playground?—and after a large group discussion, it was decided that it would be necessary to collect the animals and, subsequently, to identify and count them. To emphasize the need for a longer contact with the animals through the construction of terrariums, Helena established a direct link between

| Inquiry features                                      | Helena | Leonor | Carla |
|-------------------------------------------------------|--------|--------|-------|
| Learner engages in scientifically oriented questions | F (S/T)| S (T)  | S (T) |
| Learner gives priority to evidence in responding to questions | F (S/T)| F (T)  | F (T) |
| Learner formulates explanations from evidence         | F (S/T)| S (T)  | S (T) |
| Learner connects explanations to scientific knowledge | F (S/T)| S (T)  | S (T) |
| Learner communicates and justifies explanations        | F (S/T)| S (T)  | S (T) |

A, absent; S, sporadic; F, frequent
(T), teacher; (S), students
some of the research questions formulated by the students and the evidence needed to answer the questions: “What D. is saying is to get the animals and drop them at the end of the day. Do you think we can answer all questions with this strategy?” (FN). In other situations, the prioritization of evidence was established directly by the students as they planned the activities: we bring several boxes and then we put each kind of animal in a box and then we see what they eat (FN). In addition, in some situations, the answers were obtained through the reading and interpretation of texts produced by Helena about the animals.

The third aspect of inquiry teaching was quite imperceptible with Leonor and Carla mainly due to the discursive practice they adopted. The little support given in data organization and treatment indicates that the implementation of practical activities was essentially regarded as a tool for data collection. In other words, it seems that a more hands-on component is favored rather than the formulation of explanations based on evidence. The evaluation of the explanations and their connection to scientific knowledge was in both Leonor and Carla’s practice guided by the trainees’ themselves. However, Helena actively involved the students in the formulation and evaluation of explanations and encouraged divergent reasoning in different moments. As an example, one of the students’ groups offered different explanations for the pill-bugs’ death and compared them with the explanations found in texts collected at home. Helena also encouraged the development of different explanations for the same observations:

Helena – There are two groups studying the pill-bugs, isn’t it? … Why did some die, and others didn’t?
Student - Because our land was wet and theirs wasn’t. …
Helena - So that was why? Does that group have very dry land?
Student – Could be, but could also be for another reason, the animals were fed for fewer days.
Helena - ahhh, and they were hungrier, is that it? More ideas, D.C.? (FN).

Student communication was explored by Leonor and Carla in a very superficial manner. Overall, the questions raised by these two PST were closed questions and dialogues were teacher-student. On several occasions when students arrived at the intended answer, they went on to a new task or finished the activity that was running. The discursive practices adopted by Helena allowed a greater interaction among the students as well as a clearer communication of the learning that had taken place during the aforementioned activities. Before starting a new session, Helena always saved some time for each group to share their work. Therefore, students had the opportunity to ask their colleagues questions and to evaluate the evidence provided by the group and the reasoning they had carried out, as well as to suggest new explanations. Helena formulated challenging questions that permitted the establishment of relationships among several variables.

It is important to mention that even in an early phase of the intervention, the mentor teachers’ lack of receptiveness to the implementation of different strategies was evident in all participants’ discourse. However, this was particularly clear with Leonor, who suspected that her mentor teacher was not open to practical activities due to some comments that he made.

The extent of the syllabus was evident in the classroom where Carla taught. The great diversity of contents and the short intervention period seem to have conditioned the activities and strategies implemented. An example of such can be found when she was required to teach the water cycle in one sitting as there was a school-wide test the following day.
5.2.2 NOS Teaching

After analyzing the learning objectives formulated by the three participants, it became evident that NOS was not valued. In Leonor and Carla's lesson plans, there was a complete lack of objectives in this area and a predominance of objectives in the field of substantive and process knowledge. In Helena's case, despite the diversity of learning objectives, process knowledge and reasoning were the most valued aspects.

Finally, no evidence was found of an explicit and reflective approach about NOS in any of the participants. Only one episode was detected where Carla explicitly tried to facilitate students' understanding of the meaning of models in science. However, this episode was explored in isolation and in an incomplete manner.

In Helena's lessons, different opportunities for the development of an explicit, reflective, and contextualized NOS teaching were identified, largely as a result of the inquiry nature of the activities. To exemplify, in one lesson, students offered three hypotheses to explain why the animals in a box were near some wet cotton; they hypothesized that the animals were thirsty, sleeping, or showering. However, Helena did not use this moment to adopt an explicit and reflective approach about the empirical nature of scientific knowledge. In other words, the necessity of these interpretations to be sustained in the observations made. This would be possible through the formulation of questions such as “Are the three hypotheses equally valid?” and “What makes one hypothesis more meaningful than the other?”.

In the I3, participants reported different reasons for not adopting an explicit and reflective approach about NOS: Helena essentially referred to the lack of time, Carla the lack of NOS in the syllabus, and Leonor concern in covering all the contents. Nevertheless, Helena considered that she had implicitly focused on certain NOS aspects because she had carried out a research project which, by virtue of its characteristics, “enables children to understand what research work is, how science works, and the characteristics of scientific knowledge” (I3). However, she acknowledged that it would have been richer if she had created moments to explicitly discuss some aspects of NOS. Helena's discourse suggests that regarding the continuum between an explicit and implicit approach to the NOS, she identifies with an intermediate position. This position can be verified by her assertion: “it's a little bit in the middle … maybe there are things that they [the students] realize… because we are doing science … but maybe there are other moments that we have to explain a little better” (I3).

The pedagogical practices implemented by Helena suggest the adoption of an implicit approach to the NOS. Although she believed that it is important in some situations to adopt a more explicit approach, temporal constraints prevented her from adopting this approach during the supervised teaching practice. However, in the future and in the absence of this constraint, Helena demonstrated willingness to explicitly apply NOS concepts: “it is necessary, no doubt that it is necessary … and if I had had more time I would have gone there” (I3).

6 Discussion

This study suggests that the immersion in RSC, accompanied by reflective moments, has beneficial effects regarding PST thinking about teaching and learning science. Similar to other investigations, changes were detected in participants' conceptions towards a more inquiry teaching approach. Our participants came to emphasize the need to make science
education more authentic. Despite there being different degrees of emphasis among the participants, this appreciation was evident in both the effects reported and through the analysis of interviews and critical incidents.

The differences between the participants involved in our study suggest that the singularities of RSC play an important role in this process. When asked about what they had learned from their experiences in the program, Helena and João made specific reference to didactic and pedagogical learning. This was not the case for Leonor and Carla. In addition, to contextualize these learnings, they described episodes grounded in the RSC and connections that the scientist made between scientific research and science education, and the scientist salutary relationship with elements of the research team. The relationship between the RSC and the development of a more inquiry approach is supported by other studies. Langford and Huntley (1999) identified the nature and environment of the internships as well as the role of the mentors, as key elements for the changes identified in the future teachers involved in the RE.

The critical incident analysis also revealed that certain NOS aspects were more easily discussed by the participants than others, which was also reported in the study conducted by Wahbeh and Abd-El-Khalick (2013). According to these authors, teachers sought to exploit NOS aspects in which they had deeper knowledge. However, given that the participants of the LSP revealed informed conceptions about NOS aspects that have not been explored in the critical incidents (Valente et al., 2018), this explanation is not suitable for this case. There seem to be two more plausible reasons: (1) the participants considered that certain NOS aspects are more accessible to elementary students (Akerson et al., 2019); or (2) they felt more comfortable thinking about strategies for certain NOS aspects. In the study conducted by Akerson and Volrich (2006), the first reason was reported by a future teacher to justify the exploration of three NOS aspects (difference between observation and inference, the role of creativity and imagination, and the tentative nature of scientific knowledge) with first-year pupils.

The critical incidents also revealed differences in the approach adopted by participants regarding NOS teaching. At the end of the program, Leonor and Carla adopted a didactic approach. The proposals created by Helena and João reflect a more reflective-explicit approach where, through the promotion of questioning, they tried to help students to establish a connection between the critical incidents and NOS features. However, in some situations, they revealed difficulties in realizing their intentions.

These results seem to suggest that the LSP was more effective in the development of understanding about NOS than in the development of pedagogical content knowledge of this topic. It also reinforced the need to use instruments that do not focus only on NOS conceptions but that permit the portrayal of the complexity inherent in the teaching and learning of NOS (Nott & Wellington, 1996). The critical incidents used in this research seem to meet this purpose since they allowed us to understand the NOS knowledge which informed the participants’ intentions in hypothetical classroom situations.

Despite the changes identified in the participants’ thinking, they referred to various constraints associated with inquiry and NOS teaching. Within these constraints, it is important to highlight the immense weight given to the initial teacher training. Similar to other investigations, the influence of the mentor teacher was the most prominent aspect referred (Crawford, 2007; Fazio et al., 2010). For two participants in particular, Leonor and Carla, the implementation of some innovations seemed more feasible after the PST training.

However, in this study, less widely mentioned constraints mentioned in the literature were identified, in particular those related to the curricular context. In the Portuguese Science syllabus, no explicit reference to the importance of working NOS could be found.
Thus, contrary to the trend in many countries and the recommendations in the field of science education, the Portuguese elementary curricular context does not highlight the NOS importance.

Enderle et al. (2014) studied the teachers’ ideas about contextual factors they considered to influence inquiry teaching before and after their involvement in apprenticeship programs and concluded that there was no significant change in participants’ views. This can also be confirmed with the participants involved in our research. This is not surprising as the contextual aspects are not usually the focus of these programs and the activities are not grounded in the classroom. However, these results suggest possible areas for improvement in the design of these programs, particularly for PST training. For example, designing a program that simultaneously involves PST and mentor teachers could help minimize some of the constraints identified by the participants in these studies.

In the present research, the impact of the LSP in participants’ teaching practices was explored in two different dimensions: the adoption of an inquiry-based teaching and teaching about NOS. There was little evidence of the adoption of an inquiry-based teaching with both Leonor and Carla. The time constraints associated with the high diversity of contents to address and the need to meet the lesson plan objectives and manage students’ questions and behavior seem to have been decisive in the choices made by the participants in the classroom. In addition, the fact that the mentor teacher had different conceptions compared to the PST directly or indirectly contributed to the emergence of some dilemmas and tensions, and the adoption of a more cautious approach by the participants. In fact, one PST “may certainly be cautious in using an inquiry-based approach, when that approach is in direct contrast to one used by the Mentor” (Crawford, 2007, p. 637).

However, despite the reluctance of the mentor teacher, Helena implemented inquiry practices in her classrooms. Thus, as in the study conducted by Crawford (2007), the actions of the participants do not seem to be explained only by the mentor’s support. In other words, the influence of these professionals intersects with other variables and together these factors appear to shape the work of the PST. It is therefore necessary to analyze the peculiarities of Helena’s journey to try to identify any factors that have helped her adopt an inquiry-based teaching.

The improvement of didactic and pedagogical knowledge was one of Helena’s underlining goals regarding her involvement in the LSP. After the program, Helena was the participant who reported the greatest increase in confidence in the development of inquiry activities in the classroom. Similar to the study by Dixon and Wilke (2007), this increase in confidence seems to have been the result of a more informed view of the nature of scientific research. Additionally, evidence suggests that the role played by the scientist in the real science context (guided by the promotion of questioning and divergent thinking) contributed to increase her confidence. In different situations, she noted that just like the scientist, not knowing something was not a problem. Moreover, the role that Helena adopted in class was, at different times, very similar to the role that the scientist implements during the scientific research. This relationship between the transfer of the RE to the classroom and scientist’ role is corroborated by the research conducted by Hughes et al. (2012).

Thus, the reflective attitude evidenced by Helena, the expectations placed in the program, and the nature of the RSC contributed to the development of more informed conceptions about science and science teaching which, in turn, caused an increase in her confidence. This constellation of factors seems to have been essential to decrease the importance given to the influence of local and cultural constraints (e.g., lack of openness of the mentor teacher), and the implementation of an inquiry-based teaching became possible.
As for the NOS teaching, there was little evidence of an explicit and reflective approach in the participants’ teaching practices. The fact that the learning objectives regarding NOS were almost marginal (Helena) or non-existent (Leonor and Carla) suggest there has not been an explicit concern with NOS. Thus, although the program has contributed to the development of more informed conceptions about NOS (Valente et al., 2018), the participants did not teach about NOS, i.e., they did not aim to develop “informed epistemological understandings about the generation and validation of scientific knowledge, and the nature of the resultant knowledge” (Abd-El-Khalick, 2013, p. 2090). However, Helena created learning environments that imitated authentic scientific practice, and therefore, she taught with NOS (Abd-El-Khalick, 2013).

The non-adoption by the participants of an explicit-reflective approach to NOS instruction reinforces the idea that informed conceptions about NOS are a necessary but insufficient condition for the exploration of these aspects with the students (Abd-El-Khalick & Lederman, 2000). At this point, it should be noted that different studies have shown the importance of helping and supporting the future teachers to develop lesson plans that address the NOS and their implementation, an aspect which is not covered in the LSP. Akerson and Abd-El-Khalick (2003) accompanied an experienced elementary teacher and asserted that she “needed support to translate her NOS views and intentions into pedagogically appropriate instructional activities that would make the target NOS aspects accessible to her students” (p. 1025).

In conclusion, the transfer of the RE lived in the LSP to the classroom was somewhat limited and different constraints appear to have prevented it, namely those associated with the teachers’ initial training, the Portuguese educational context, the participants’ ideas about the students’ abilities, and the participants’ fear and inexperience. Considering the nature of these constraints, it becomes clear that any change in the practice of future teachers requires a global and comprehensive effort by the different stakeholders in the educational process. For this reason, future investigations similar to the LSP should be extended to the first years of teaching. It is possible that in the absence of some of the constraints identified, it would be possible to have a clearer idea of the potential of these programs in transferring RE to the classroom. Although the conclusions of this study are based on data about only four teachers, few studies have made such a close and detailed analysis of the process lived by future teachers during research experiences in RSC, which can contribute to the development and implementation of these types of programs in the preservice teacher education.

Appendix

Appendix I. Initial semi-structured interview (I1)

Participants’ conceptions of science teaching and learning

- Describe what you believe is a good science lesson.
- Which strategies do you think are more appropriate to teach science? Why? Which are the most inappropriate?
- How do you think students learn science?
– What skills should children develop in their science classes? (in terms of knowledge; processes; attitudes, values)
– In your opinion, why elementary students should learn science? What is the purpose of science education?

Appendix II. Examples of critical incidents

| Critical Incidents | Illustrative examples of responses |
|--------------------|----------------------------------|
| After Easter holiday, students of 4th grade and their respective teacher were extremely sad and surprised when they realized their class fish had died. The teacher used the event and asked the pupils to investigate the causes of its death. The students, divided into 3 groups, come to different conclusions. After presenting the conclusions one of the students said: “teacher, but after all what is the right answer?” Say what you would do, or say, in this situation and why NOS features: Tentative NOS; Creative and imaginative NOS; Difference between observation and inference; Empirical NOS | I would not know what to do in this situation. I wouldn’t probably know why the fish had died … I wouldn’t be aware of what had happened … maybe I’d do some research, I don’t know, I don’t know. I wouldn’t know the reason of its death … I don’t know, if maybe I knew the right answer I would say it to the pupils, but not knowing perhaps I would accept the 3 possibilities, because if I didn’t know I wouldn’t be able to select one. Interviewer – just for curiosity, would you remember to suggest this task to your students in a similar situation? Honestly, I don’t think I would ask them to research the causes of death … because I wouldn’t know what answer to give |
| To start the study of the solar system a primary teacher displayed an old poster on the wall. After placing it she realized Pluto was represented as a planet in the solar system and immediately said: “This celestial body is no longer considered a planet”. One student said: “But it is represented on the poster! If it has been a planet it doesn’t make sense to go back! Scientists shouldn’t change their opinion! Poor Pluto!” Say what you could do and say in this situation NOS features: Tentative NOS; Inference and theoretical entities | I would say that instruments to observe the solar system change over time becoming more powerful and allowing us to have a better view of the planets. Pluto was once regarded as a planet but nowadays thanks to the new technologies is no longer a planet, this is not a matter of opinion changing but is linked to a new and real observation. I would analyze the conclusions of each group, each group had to defend their conclusions, i.e., we think that the fish died because of this, and this, then we’d look if their ideas were plausible, or not, and therefore we could eliminate some conclusion, I think so, for example, if one group said the fish died because it hadn’t enough food and we knew that the security guard had been there to feed the fish everyday then we would exclude that hypothesis. I would want to understand how they reached to those conclusions. We would never know the real reason for its death but promoting this debate would be very interesting, wouldn’t be? Interviewer – just for curiosity, would you remember to suggest this task to your students in a similar situation? I think so…I think it could be quite an interesting project… I think so. I would try to visit the planetarium with them … but if it wasn’t possible … I think students need to understand what characteristics planets have and why Pluto was once considered a planet and the features it has for no longer being considered a planet … maybe there are more than two definitions of planet … so I would probably try to do some research with them on the various definitions of a planet over time |
Appendix III. Semi-structured interview after the LSP (I2)

General characterization of the Program

– Overall, how do you characterize the program?
– What kind of emotions do you associate with the program? (Are they different when you think about the apprenticeship or when you think about the seminars?).
– Have your expectations regarding the program been met?
– What is the aspect that you consider most relevant regarding your participation in the program?
– In your opinion, did you learn or gain something from the program? (in the apprenticeship; in seminars)?
  If so, what do you think you have learned? What kind of learning do you think you have developed by participating in this program? Can you give me examples of how the program affected you?
– What difficulties did you encounter (in the apprenticeship, in the seminars)?

Participants’ conceptions of science teaching and learning

– Describe what you believe is a good science lesson
– Which strategies do you think are more appropriate to teach science? Why? Which are the most inappropriate?
– How do you think students learn science?
– What skills should children develop in their science classes? (in terms of knowledge; processes; attitudes, values)
– In your opinion, why elementary students should learn science? What is the purpose of science education?
– What effect do you think this experience may have on your future practice in science education? What changes do you hope to implement in your future teaching practices as a result of this contact? (type of activities, time devoted to them, etc.) Why?
– Do you think there is a parallel between the things that researchers do and the activities that students normally carry out in the scope of science teaching?
– In any situation, didactic-pedagogical aspects were discussed with the researcher? If so, can you give me examples?
– Did this experience make you more or less interested in science?

Appendix IV. Semi-structured interview after completion of the supervised teaching practice (I3)

Overall assessment of the implementation of science activities

– What do you think went well during the science lessons? And what went wrong? Why?
– What difficulties did you experience?
– Would you make any changes to the way you planned and implemented the activities? Can you justify?

NOS and inquiry teaching
Examples for Carla

- The group work was valued during the first two activities but not in the last two. Why?
- You always indicated the lesson goal, but you never formulated or asked students to formulate a question to be answered through the practical work. Why?
- During the soils’ exploration, students did not always agree with the characteristics of the soil. In those cases, they called you and you indicated the answer. Why?
- During the water cycle model, you spent some time exploring the relation between the model and reality. However, you only explored the common aspects. Why?
- Your lesson goals were mainly concerned with scientific knowledge. NOS and SI were not present in the lesson goals. Why?

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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