

---

## Infusing epistemic perspectives on scientific practices in science teacher education

Sibel Erduran, Deniz Saribas and Ebru Kaya

---



### Electronic version

URL: <https://journals.openedition.org/educationdidactique/12227>  
DOI: 10.4000/educationdidactique.12227  
ISSN: 2111-4838

### Publisher

Presses universitaires de Rennes

### Printed version

Date of publication: December 1, 2023  
Number of pages: 75-92  
ISBN: 978-2-7535-9719-8  
ISSN: 1956-3485

### Electronic reference

Sibel Erduran, Deniz Saribas and Ebru Kaya, "Infusing epistemic perspectives on scientific practices in science teacher education", *Éducation et didactique* [Online], 17-3 | 2023, Online since 01 January 2026, connection on 16 January 2026. URL: <http://journals.openedition.org/educationdidactique/12227> ; DOI: <https://doi.org/10.4000/educationdidactique.12227>

---



The text only may be used under licence CC BY-NC-ND 4.0. All other elements (illustrations, imported files) may be subject to specific use terms.

# INFUSING EPISTEMIC PERSPECTIVES ON SCIENTIFIC PRACTICES IN SCIENCE TEACHER EDUCATION

Sibel Erduran

University of Oxford, United Kingdom & University of Bologna, Italy,  
identifiant ORCID : 0000-0001-5226-0136

Deniz Saribas

Istanbul Aydin University, Türkiye, identifiant ORCID : 0000-0002-4839-7858

Ebru Kaya

Bogazici University, Türkiye, identifiant ORCID : 0000-0002-9506-7608

The paper provides a case for the inclusion of epistemic perspectives on scientific practices in science teacher education. Scientific practices are defined as being part of nature of science and are drawn from the account of the Family Resemblance Approach (FRA) developed by Erduran & Dagher (2014a). The depiction of scientific practices relies on a theoretical model called the Benzene Ring Heuristic (BRH) which consolidates the epistemic, cognitive and social aspects of scientific practices into a holistic and visual representation. BRH describes scientific practices in terms of concepts such as data, models, explanations, predictions, argumentation and social certification. We describe a funded project that integrated BRH into a pre-service science teacher education program and investigated the impact of the intervention on the pre-service science teachers. Qualitative analysis of pre-service science teachers' perceptions of scientific practices are described and contrasted before and after the training intervention using BRH. The results indicate that in some cases there was improvement in pre-service science teachers' depiction of scientific practices as being holistic. The study provides empirical evidence on the incorporation of an epistemic perspective on scientific practices in science teacher education.

Keywords: Epistemic perspectives, Teacher education, Nature of science, Family Resemblance Approach

## *Intégrer des perspectives épistémiques sur les pratiques scientifiques dans la formation des enseignants en sciences*

*Ce texte plaide en faveur de l'inclusion de perspectives épistémiques sur les pratiques scientifiques dans la formation des enseignants en sciences. Les pratiques scientifiques sont définies comme faisant partie de la nature de la science et sont issues de l'approche "Air de Famille" (FRA) développée par Erduran & Dagher (2014a). La représentation des pratiques scientifiques repose sur un modèle théorique appelé Benzene Ring Heuristic (BRH) qui consolide les aspects épistémiques, cognitifs et sociaux des pratiques scientifiques dans une représentation holistique et visuelle. La BRH décrit les pratiques scientifiques en termes de concepts tels que les données, les modèles, les explications, les prédictions, l'argumentation et la certification sociale. Nous décrivons un projet financé qui a intégré la BRH dans un programme de formation initiale des enseignants en sciences et qui a étudié l'impact de l'intervention sur les enseignants en sciences en formation initiale. L'analyse qualitative des perceptions des pratiques scientifiques par les enseignants de sciences en formation est décrite et comparée avant et après l'intervention de formation utilisant la BRH. Les résultats indiquent que dans certains cas, les enseignants de sciences en formation ont amélioré leur représentation des pratiques scientifiques comme étant holistiques. L'étude fournit des preuves empiriques de l'intégration d'une perspective épistémique sur les pratiques scientifiques dans la formation des professeurs de sciences.*

*Mots-clés : Perspectives épistémiques, Formation des enseignants, Nature de la science, Approche par ressemblance familiale*

The project reported in this paper was led by Sibel Erduran whose tenure at Bogazici University, Istanbul, Turkey was supported by a TUBITAK and European Union Marie Curie Co-Fund Brain Circulation Scheme Fellowship (291762/2236). The project was entitled “Revisiting Scientific Inquiry in the Classroom: Towards an Interdisciplinary Framework for Science Teaching and Learning.”

## INTRODUCTION

Arguments for the incorporation of epistemic perspectives on science in science teacher education have been made within science education policy and research across the world for some time. Various constructs related to epistemic practices such as “scientific inquiry” and “scientific practices” have been advocated, developed and investigated. For example, Inquiry-Based Science Teaching (IBST) has featured in the European Commission’s “Rocard Report” which recommended:

A reversal of school science-teaching pedagogy from mainly deductive to inquiry-based methods provid[ing] the means to increase interest in science” and teacher networks to “allow[s] them to improve the quality of their teaching and support[s] their motivation (Rocard et al., 2007, p. 11).

Apart from policy arguments for the inclusion of inquiry in science teaching, substantial amount of research has been conducted by science educators to identify effective strategies for its implementation (e.g., Anderson, 2002). Scientific inquiry is what scientists do when they attempt to understand the natural world by asking questions about systems or objects, by collecting data, making predictions, testing out ideas and making conclusions. Even though school science is not precisely the same as professional science, and children are not exactly scientists, a scientific way of thinking is an important component of understanding scientific processes and becoming a scientifically literate citizen. Placing inquiry at the heart of school science is what models of inquiry-based science teaching set out to do, by creating opportunities for students to engage in asking questions and investigating the world around them.

The roots for inquiry-based learning may be found in early versions of progressivism (Schwab 1964) and later versions of constructivism and social constructivism (Lemke 2004, Driver et al., 1996). The post-sputnik era of curriculum reform in the United States and Europe saw the reconstruction of science teaching aimed at moving students away from passive roles of learners to more active participants in the learning process. Projects such as Nuffield science in England and SCIS (Science Curriculum Improvement Study) in the United States introduced and implemented ideas of activity-based science where exploration and curiosity preceded the introduction of new concepts. Decades later we continue to question both the content of science curricula as well as the way we teach science in schools. Science in society, the processes of science, authentic science, ICT and recently socio-scientific issues and argumentation are movements that have dominated science curriculum frameworks in secondary science education (Jorde & Dillon, 2012). It may be argued that there is no one correct definition or unified concept for inquiry-based learning methods in science education. Generally, the concept refers to learning and instruction designs that engage students in active and authentic problem-solving activities that pay attention to diagnosing problems, critiquing experiments, distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments.

A more recent construct relates to “scientific practices” which has gained much popularity particularly in the USA. Research Council (NRC, 2012) of National Academy of Sciences designed a Framework for K-12 Science Education in order to create standards of science education which include some epistemic components. According to the *Next*

*Generation Science Standards* (Achieve Inc., 2013), scientific practices refer to asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematical and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information. A significant aspect of scientific practices is that science learning is more than just about learning facts, concepts, theories, and laws. A fuller appreciation of science necessitates the understanding of the science relative to its epistemological grounding and the process that are involved in the production of knowledge (Hogan & Maglienti, 2001; Wickman 2004). The argument is that such practices in the science curriculum helps students understand the scientific knowledge development, the way scientists work, and may increase students' cognitive abilities (NRC, 2012). However, science curriculum by itself may not be enough for understanding and experiencing of scientific practices. Teachers as the major actors of learning environment should also have an understanding of scientific practices (Zemba-Saul, 2009).

In this paper, we focus on the epistemic dimensions of “scientific practices” and how they can be incorporated in science teacher education. Following a review of a particular characterisation of scientific practices derived from Erduran and Dagher's (2014a) work, we present an empirical study conducted with pre-service science teachers in Turkey. The empirical study aimed to investigate pre-service science teachers' views of scientific practices in the context of a course designed to incorporate the epistemic dimensions of scientific practices in teacher preparation. Details of the training are outlined, and the findings illustrate the changes in pre-service teachers' perceptions of scientific practices. The discussion begins with a review of the notion of “scientific practices” in science education which provides the theoretical background of the empirical study.

### Scientific practices in science education

The policy initiatives in the USA have led a shift away from science inquiry and towards the inclusion of scientific practices (Duschl & Bybee, 2014). As Bybee (2014) argues, by engaging students in scien-

tific practices, we involve students in understanding NOS. Science as a practice and scientific practices as a term emerged within philosophy of science. Kuhn refers to the processes in which the scientists engage during knowledge production and communication. Historians, philosophers, and sociologists of science (Latour, 1987/1989; Longino, 2002; Nersessian, 2008) argued that the scientific practices include, among others, theory development and specific ways of talking, modeling, and communicating the outcomes of science. It is beyond the scope of this paper to provide a detailed account of scientific practices in science education. Rather, we focus on a particular framework from the work of Erduran and Dagher (2014a) which will form the basis of the training intervention in the empirical study described in the rest of the paper.

Erduran and Dagher (2014a) discuss the nature of science using the Family Resemblance Approach (FRA). In this framework, NOS is characterised as a cognitive, epistemic, social and institutional system. FRA different fields of science such as chemistry, physics and biology in terms of the resemblances. For example, all fields of science aim to achieve accuracy of data. However, there may also be domain-specific differences between different fields of science. For example, what counts as observation in astronomy and chemistry will be nuanced (Irzik & Nola, 2014). FRA has thus been advanced as a framework to characterise NOS on the basis of a set of resemblances among the sciences given the historically difficult problem of demarcation of science from non-science or pseudo-science. In other words, by focusing on NOS as a “family” of characteristics shared by different domains, FRA justifies why a field is called ‘science’. Different aspects of NOS are represented in FRA categories, such as the aims and values, methods, practices, knowledge and social context. It is the resemblances among these categories that warrant the depiction of a field as ‘science’. FRA has been used in science education to develop strategies for teacher education (Kaya et al., 2019), undergraduate teaching (Petersen et al., 2020) as well as an analytical tool for examining science curricula (Yeh et al., 2019) and assessments (Cheung, 2020). Students' understanding of nature of science (NOS) has been investigated from an FRA perspective at elementary (Akbarak & Kaya, 2020) and university level (Akgun & Kaya, 2020). A series of studies have been conducted focusing on the analysis

of textbooks on their coverage of NOS (BouJaoude, Dagher & Refai, 2017; Park, Yang, & Song, 2020). More recently, an issue of the journal *Science & Education* has been dedicated to the recent developments on the applications of FRA in science education (Barak, 2023).

“Scientific practices” is one of the FRA categories in Erduran and Dagher’s (2014a) characterisation of NOS. These authors argue that “scientific practice” is a term that engages skills and knowledge meaningfully to make scientific investigation. In this respect, it is more comprehensive than the term science process skills. In other words, scientific practices do not only involve practicing skills but also refer to making sense of the relationship between skills and underlying scientific content knowledge and epistemology. In order to appreciate the nature of scientific knowledge one has to both understand and experience scientific practices. Hence scientific practices were also emphasized as part of understanding nature of science studies (Irzik & Nola, 2014; Erduran & Dagher, 2014).

Benzene Ring Heuristics (BRH) is a theoretical tool that was developed to frame how scientific practices may be approximated for the purposes of science education (Erduran & Dagher, 2014a). BRH model includes epistemic, cognitive and social components. Epistemic components refer to scientific activities, data, real world, model, explanation, and prediction. These components also refer to the features of the scientific practices. Cognitive and social components respectively refer to representations and reasoning and social dissemination and certification of scientific claims. BRH suggests that all features of scientific practices are related to each other and these relationships do not have a linear order. In other words, holistic understanding of scientific practices was emphasized with the representation referring to an analogy that is Benzene Ring. In this heuristic, components of scientific practices represent the atoms and the social components (representation, reasoning, discourse, social certification) stand in the place of electron clouds (See figure 1). This model in is inclusive of the components of science, the nonlinear relationships between these components and a holistic understanding of science. Therefore, Erduran and Dagher (2014a) argue that the BRH makes a contribution overcoming the procedural understanding of science with its holistic approach.

Given BRH is a theoretical heuristic by nature, we wanted to explore the implications of its implementation in practice, specifically in a teacher education context. Here we will review its adaptation to science teacher education and describe a funded research project in Turkey.

## METHODOLOGY

### Research questions

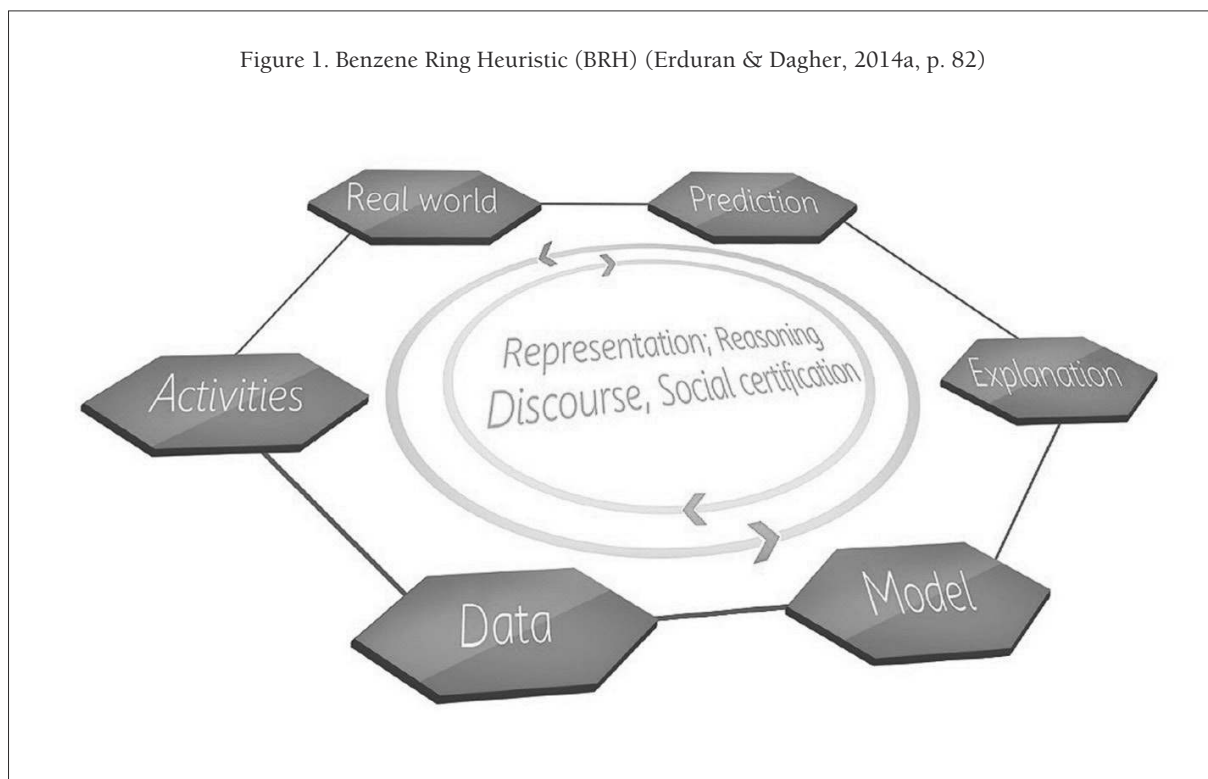
The empirical study was guided by the following research question: *How do pre-service science teachers perceive scientific practices, particularly having been introduced to scientific practices in a university teacher education course?*

### Participants

The study will be described in two parts. The first part of the study was conducted with 11 pre-service science teachers (1 male and 10 females) in a 4-year science teacher education programme in Turkey. These pre-service science teachers, who were in the third year of teacher training were being trained to teach science in secondary schools. Primary, secondary and high schools in Turkey each have four grades. Pre-service teachers who are the participants of the study will teach the following science topics in 5th, 6th, 7th and 8th grades: solar system, seasons and climate, energy conversions and environmental science, living things, cell and cell division, systems in human body, DNA and genetic code, pressure, force and motion, matter, heat and industry, sound and its characteristics, interaction of light with matter, electricity and electrical circuits, simple machines. The participants were purposively selected among 36 pre-service science teachers enrolled in the course titled “Laboratory Applications in Science Education”.

In the second part of the study, we focus on 3 pre-service science teachers consisting of one male and two females selected among 11 pre-service science teachers. These 3 cases were selected based on the improvement levels in their perceptions of scientific practices. These levels are a lot of improvement

Figure 1. Benzene Ring Heuristic (BRH) (Erduran &amp; Dagher, 2014a, p. 82)



(Case 1), some improvement (Case 2), and minimal improvement (Case 3). Moreover, the course instructor suggested these pre-service teachers as representatives of all participants. The course included three-hour lecture and two-hour lab work. The second author was the instructor of the lecture hours, and a research assistant supported the participants during the laboratory hours. The course was taught in English which was the second language of the participants.

### Training intervention

The intervention consisted of 3 training workshops about scientific practices, BRH and their pedagogical use, and lasted 3 weeks. Before the intervention, the pre-service teachers engaged with the discussions of safety, science process skills, inquiry-based teaching, instructional types and different pedagogical approaches, ranging in a very traditional instruction to an open-inquiry teaching in laboratory education. At the beginning of the course the pre-service teachers formed groups of three or four participants to design and implement their lesson plans (LPs).

They came together with their group mates during laboratory hour and worked on their LPs in the assistance of the research assistant. Ten volunteered pre-service teachers were interviewed before and after the intervention. Table 1 shows the details about the workshops. Each workshop consisted of three lecture hours and two laboratory hours per week. The pre-service teachers worked in their groups to incorporate each theme into their own LPs with the help of a laboratory assistant.

The first session aimed at introducing pre-service science teachers' SPs and BRH depending on an acid-base activity. The activity was designed by the project team to provide an example of BRH. For example, data were discussed as pH values of acids and bases which react to produce neutral salts. The chemical reaction of neutralisation was presented as an example of modelling to explain what happens when acids and bases interact. This session began with the discussion of SPs and creating a concept map in groups by using these practices in order to reveal their initial understanding of acids, bases and neutralisation. In the acid-base activity they tested different substances by using their sense (i.e., see, smell, taste, and touch). Then they recorded their

Table 1. The aims, main themes, and content of the pre-service teacher training workshops.

Workshop	Aim	Main Theme	Content
1	To engage pre-service teachers in a discussion on scientific practices	Introducing Scientific Practices	Pre-service teachers: <ul style="list-style-type: none"> <li>– designed posters to represent their ideas about scientific practices at the beginning of the workshop before the taught content;</li> <li>– carried out the “Acids and Bases” activity to situate scientific practices in the context of a school lesson example;</li> <li>– were introduced to BRH;</li> <li>– discussed activity in the light of BRH.</li> </ul>
2	To consolidate understanding of BRH and to start designing lesson planning	Adapting BRH to Lesson Planning	Pre-service teachers: <ul style="list-style-type: none"> <li>– discussed components and relationships of scientific practices based on their activities;</li> <li>– incorporated their activities into lesson plans;</li> <li>– reflected upon their lesson plans in terms of teaching scientific practices.</li> </ul>
3	To engage the participants in reflection, model evaluation and revision.	Implementing pedagogical strategies to teach scientific practices	Pre-service teachers: <ul style="list-style-type: none"> <li>– were introduced with three lesson plans with different pedagogical approaches; (e.g. verification, open-inquiry);</li> <li>– evaluated the lesson plans in terms of scientific practices;</li> <li>– revised their previous lesson plans;</li> <li>– designed posters to represent their ideas about scientific practices.</li> </ul>

findings in a data table and finally they drew a model indicating their understanding of acids and bases and its properties in groups. This session ended up with the discussion of SPs used during this activity and introducing BRH. Links between each SP and the pre-service teachers’ ideas were also discussed during introducing of BRH.

The aim of the second session was to adapt BRH to lesson planning in order to strengthen their understandings of SPs and BRH. For this purpose, each groups chose a science topic and created an outline of a LP by using SPs based on BRH. The participants discussed connections between the different examples as well as across each of the SPs

and reflected on their understandings of SPs and how the work helped them understand lesson planning. The purpose of the third session was to let the pre-service science teachers evaluate and revise earlier models by using three different examples of lesson plans, each of which was on different topics based on different instructional styles. The first example was on the topic of phases of matter, and it was a verification (traditional) type of laboratory instruction. The second was about creating an aquatic ecosystem based on guided-inquiry approach. The third was building a model investigating the behaviour of earth’s crust and it was designed as an open-inquiry approach. Pre-service science teachers evaluated

these three examples of LPs in terms of SPs. The session ended up with the plenary discussion of the revision of the models. Finally, they constructed concepts maps and compared them to their initial maps.

### Data Collection

In order to assess pre-service science teachers' perceptions of scientific practices, 8 interview questions were prepared (see Appendix A). These questions were related to scientific practices. In particular, features of scientific practices, relationships between scientific practices, scientific practices different fields of sciences and teaching of scientific practices were the key themes that underpinned the questions. The questions were used for both pre- and post-interviews. The first and third authors conducted interviews one week after the implementation of all 3 workshops.

### Data Analysis

The qualitative data analysis was used to analyze the data gathered from pre- and post-interviews. First, the pre- and post- interview data were transcribed. Then, the codes were generated from the data. Finally, the themes reflecting pre-service science teachers' perceptions of scientific practices were identified by classifying the codes. The main themes are as follows:

- Scientific practices
- Basic features/properties of the scientific practices
- Domain-specificity related to scientific practices
- Application of scientific practices in curriculum and/or schools
- Challenges to teaching scientific practices

After tracing pre-service teachers' perceptions through both pre- and post- interviews, any potential changes in pre-service teachers' perceptions about scientific practices were highlighted. In the second part of the analysis, three pre-service teachers were selected to explore how their perceptions of scientific practices might have shifted following the training intervention.

## RESULTS AND FINDINGS

The results are presented in three sections. The first section covers overall trends in pre-service teachers' pre- and post-perceptions of scientific practices including frequency of the codes. The second section illustrates the thematic distributions in changes in pre-service teachers' perceptions of scientific practices including their perceptions related to scientific practices in curricula and challenges in teaching scientific practices. The third section focuses on 3 pre-service teachers to highlight in more depth some of the issues that emerged from the impact of the intervention on particular participants.

### Overall trends in changes in pre-service science teachers' perceptions

Table 2 indicates the codes related to pre-service science teachers' perceptions of SPs determined in the pre- and post- interviews. For each code, the frequency value is presented in this table. These values were written in the parentheses for each code. The first number represents the number of pre-service teachers who expressed the code before the intervention, while the second number refers to the numbers after the intervention. For example, perception of SPs consisted of the codes such as activities, model, data and discourse. In the pre-interviews, 9 pre-service teachers referred to "activities" as a SP while in the post-interviews the number of the pre-service teachers who referred to this code was 10. Although nobody mentioned real world, explanation, and prediction as a SP in the pre-interview, the results show that 6 pre-service teachers referred to real world, 6 of them referred to explanation and 4 of them referred to prediction in their post interviews.

Regarding the basic features of SPs, in the pre-interview, 3 pre-service science teachers thought that there is a specific order between SPs. However, in the post interview, the number of the pre-service teachers thought that there is no order between SPs was 5. Therefore, it can be said that pre-service teachers improved their perceptions of SPs with respect to the relations between SPs. This result is not surprising since the issue of order of scientific practices was explicitly mentioned as part of the BRH during the intervention.

Table 2. Comparison between pre- and post-interview results with respect to pre-service teachers' perceptions of SPs

Scientific Practices (SPs)	2023-11-20T13:06:00SE I am not sure why these are highlighted in red? They need to be all the same colour - black - in the table. <b>Basic features/properties of SPs</b>		Domain-specificity related to SPs		Application of SPs in curriculum and/or lessons		Challenges to teaching SPs				
	Pre	Post	Pre	Post	Pre	Post	Pre	Post			
Activities	9	10	Subject	1	4	Sufficient activities in textbooks	1	4	Students' & parents' attitude	0	1
Model	2	8	Data	0	1	Problems in scientific thinking	0	1	Modeling	0	1
Data	5	9	Methods	6	2	Negligence of students' level	0	1	Education and exam system	0	1
Real world	0	6	Applications	8	0	Problems in constructing hypothesis	0	1	Teachers' properties	0	3
Explanation	0	6	Equipment/Materials	3	0	Insufficient explanation in textbooks	0	1	Materials & equipment	6	2
Prediction	0	4	Goals	1	0	Insufficient assessment	0	1	Safety	4	3
Discourse / social certification	2	6	Error rate	1	1	Modeling	0	1	Students' thinking skills	1	0
Interpreting results	1	0	Ethics	2	1	Cookbook activities	0	2	Assessment	1	0
Investigation	3	0	Testable	2	1	Lack of interpretation	1	0	Ethical issues	1	0

Scientific Practices (SPs)	2023-11-20T13:06:00SE I am not sure why these are highlighted in red? They need to be all the same colour - black - in the table. <b>Basic features/properties of SPs</b>		Domain-specificity related to SPs			Application of SPs in curriculum and/or lessons		Challenges to teaching SPs		
	2	2	1	2	1	0	1	0		
Constructing hypothesis		Leads to new questions	1	0	Not sure	1	0	Keeping students' attention	1	0
		Intelligible	1	0	Not taught sufficiently	6	2	Over-loaded content	1	0
		Applicable	1	0	Depends on teacher and/or lesson	2	1	Students' leve	2	0
		Observable/measurable	3	0				Physical conditions	4	4
		Use of equipment	2	0				Time	2	2
		Concrete information	2	0				Cookbook activities	1	1
		Begins with a question	1	1						

The codes emerged as perception of application of SPs in curriculum and/or lessons were “not taught sufficiently”, “depends on teachers”, “sufficient activities in textbooks” and so on. In addition to these codes, the pre-service teachers mentioned insufficient applications of SPs such as “problems in scientific thinking”, “negligence of students’ level”, “insufficient explanation in textbooks” and “cookbook activities”. In the pre-interviews only 1 pre-service teacher said that there are sufficient activities in textbooks, in the post-interviews 4 pre-service teachers referred to this issue. Moreover, 1 pre-service teacher mentioned about modeling as an application of SPs. These observations can be interpreted as an improvement. It is interesting to note that more participants mentioned domain-specific aspects of SPs before implementation. For example, 8 participants mentioned that different sciences use different applications of SPs before the workshops, while none of the participants mentioned the applications of SPs. One participant mentioned the error rate of SPs and again 1 participant mentioned different goals of using SPs before workshops. The same participant mentioned the error rate of SPs after implementation. However, it was not clear what the participants meant by errors and the goals of SPs.

Furthermore, 6 and 2 participants mentioned different methods related to SPs before and after implementation respectively. These participants seemed to be confused about the methods used in different sciences and the specific practices used in different sciences. Four participants explained that different SPs are used in different subjects after the workshops, while only 1 participant made this explanation before the workshops. Similarly, 1 participant mentioned that different data sources can be collected by using the same SPs in different domains of science after implementation, whereas none of the participants made this explanation before the workshops. The results suggest that more participants seemed to have holistic understanding of what SPs are and how they can be used in different sciences. Related to perceptions of challenges to teaching SPs, the codes such as “safety”, “time”, “physical conditions”, “materials & equipment”, and “cookbook activities” emerged in both pre- and post-interviews. Some codes such as “assessment”, “students’ level”, and “over-loaded content” were found in only pre-interviews, while others such as “teachers’ properties”, “students’ and parents’ attitudes”, and “modeling” were found in only post-interviews.

### Thematic distribution of changes in pre-service teachers’ perceptions

The codes are related to pre-service science teachers’ perceptions of (a) scientific practices, (b) basic features/properties of the scientific practices, (c) domain-specificity related to scientific practices, (d) application of scientific practices in curriculum and/or lessons, and (e) challenges to teaching scientific practices. These codes will be described in detail in the following sections.

#### *Perceptions of Scientific Practices (SPs)*

The interviews began with the question “*what comes to your minds when we say scientific practices?*” The researchers intended to probe the participants’ general perceptions of SPs by asking this question. Various codes emerged from the participants’ responses during both pre- and post-interviews. Interviews revealed that although the participants had some understanding of SPs before intervention, they listed more components of SPs that are specified in BRH after intervention. The ‘activities’ such as observation, classification and experimentation were the most frequently emphasized component both during pre- and post-interviews (9 and 10 respectively). During pre-interviews 5 participants mentioned the component of ‘data’, while 9 participants did so during post-interviews. The number of interviewees who focused on ‘model’ (2 during pre- and 8 during post-interviews) and ‘discourse / social certification’ (2 during pre- and 6 during post-interviews) increased after intervention. The number of interviewees who listed ‘constructing hypothesis’ was 2 at both pre- and post-interviews.

None of the interviewees talked about ‘prediction’ and ‘explanation’ before intervention, while the number of the participants who listed ‘prediction’ and ‘explanation’ were 4 and 6 respectively as the components of SPs during post-interviews. The treatment seems to have been beneficial for enabling pre-service science teachers to appreciate the role of these two components in a scientific process. Other codes that emerged from the participants’ responses were ‘investigation’ and ‘interpreting results’ (3 and 1 respectively) during pre-interviews, while none of the interviewees listed them during post-interviews. The participants might have considered ‘investiga-

tion' as to have been included in the component of 'activities' and 'interpreting results' as in 'explanation' after treatment. It can be inferred from the participants' explanations that the presentation of SPs and BRH during sessions helped pre-service science teachers to think SPs in more organized manner. One of the participants' expressions of her ideas about SPs during pre-interview is quoted as follows:

Mostly experiment comes to my mind. The experiments that we make after learning the topic... to verify the facts we learned during lecture... Considering my major, education laboratory activities comes to my mind. Nothing else...

The code 'activities' emerged from this response. The same participant answered the same question by referring BRH during post-interview as quoted below:

Benzene hexagon diagram that we were introduced during sessions comes to my mind. Data, real world, experiment, model, discussion...

It is evident from the quotation above that those five components, namely 'data', 'real world', 'activities', 'model', and 'discourse / social certification' of BRH were part of the participant's perception of scientific practices.

### *Perceptions of basic features/properties of SPs*

The codes of this theme emerged from the responses for the questions that ask what the interviewees think are the basic features/properties of SPs. The aim of asking these two questions was eliciting the participants' perception of the particular components of SPs and seeing how they relate these components. Various features were emphasized by the participants during both pre- and post-interviews. However, the most prominent feature that was emphasized by the participants was the order of the components of SPs. Three out of 10 interviewees thought that there is an order in the sequence of the components of SPs before intervention while only one participant mentioned it during post-interviews. Nevertheless, during post-interviews 5 of the participants emphasized that

there is no strict order in scientific processes. The intervention seems to have influenced pre-service science teachers' holistic understanding of SPs as they specified the interrelated feature of SPs after intervention.

Before intervention only 1 interviewee specified the importance of 'providing evidence' for arguments while two of them mentioned it after intervention. Although this is a very slight increase, the intervention may have an effect on this increase because the interviewees were more likely to have an understanding of the interrelated feature of the components of SPs. During pre-interviews none of them expressed the connection of the components of SPs, but during post-interviews two participants emphasized this issue. The following 2 interviewees explained these connections during the post-interviews:

As I see from the activities we did during the sessions, we are inspired by the real world. We gather data and create a model. Then we make an experiment about it. We predict and make discussion. However, this order may change. There's not a strict order. For example, first we can make experiment and then we can make comparison with the real world. Or there can be an inference directly from the real world.

There is no a strict order. First of all we can construct a model. Then we can make activities. Or after completing all the practices we can make a model. You can make explanation depending on the model. I mean there's not a particular sequence.

These two quotes about the connections of the components of SPs also provide evidence for the improvements of the participants' holistic understanding of SPs. Other features, such as ethics, utility and curiosity were also discussed by 2, 1 and 3 interviewees respectively before intervention and 1, 2 and 1 interviewees respectively after intervention. However, these features do not seem to reveal the impact of intervention on pre-service teachers' understanding of SPs because they were not discussed during instruction and interviewees do not relate these issues to BRH.

### *Perceptions of application of SPs in curriculum and/or lessons*

During interviews the participants were asked whether they think that SPs are taught in lessons and they are part of the science curriculum. The number of participants who thought that SPs are not taught sufficiently in lessons are 6 before intervention while this number decreased to 2 after the intervention. Only 1 interviewee told that she is not sure about this issue before intervention. The interviewees focused on a particular component of SPs by discussing the extent to which these practices take part in curriculum and their application in science lessons. Following explanation made by a participant during pre-interview is given as an example:

I don't think so. In lessons teachers often give the problem and the procedure of the experiment to the students and they don't let the students interpret the results. I think the SPs of interpreting results in insufficient in lessons.

The explanation quoted above was coded as 'lack of interpretation'. Only one participant talked about this drawback during pre-interviews, while no one mentioned it during post-interviews. Another participant responded to the same question during pre-interviews as follows:

It depends on teacher. My teacher was very good in this respect. We observed everything, made all kinds of experiments. We learned how to use laboratory and had laboratory discipline. During university years, I saw that there are people who do not have enough knowledge as I have although we studied in the same years with the same books. This situation is up to the teacher's initiative.

These kinds of explanations were coded as 'depends on teacher and/or lesson.' Two participants mentioned this limitation before the intervention. However, only one participant talked about it after intervention as quoted below:

SPs are involved in curriculum. However, their application depends on school and teacher. There is not a sufficient system for controlling and evaluating their application. Real world is mostly emphasized in schools.

During the post-interview one participant discussed the efficiency of textbooks regarding SPs as follows:

The experiments and questions in textbooks are good. It's a good decision not to give information in textbooks.

Such expressions were coded as 'sufficient activities in textbooks'. The number of the participants who listed this code increased from 1 to 4. The following quotation from another interviewee indicates a questioning of inquiry level of science teaching in schools during the post-interview:

SPs are not taught in schools and universities as efficient as we learned during the workshops. Schools follow a particular procedure. They are taught in recipe-like manner.

This quote was coded as 'cookbook activities'. None of the participants mentioned it during pre-interviews while 2 interviewees talked about this problem after the intervention. The number of other codes, namely, 'problems in scientific thinking', 'negligence of students' level', 'problems in constructing hypothesis', 'insufficient explanation in textbooks', and 'modeling' were 1 for each at the post-interviews. However, none of the participants listed these codes during pre-interviews. Various limitations of the applications of SPs were emphasized both in pre- and post-interviews. However, it is evident that the number of codes that emerged from the participants' explanations increased after intervention. It can be inferred from these results that introducing SPs by presenting BRH helped the pre-service science teachers interpret and evaluate the application of SPs in lessons and the curriculum.

### *Perceptions of challenges to teaching SPs*

The interviewees were asked whether they see challenges to teach SPs in science lessons and if so, in what sense? Various challenges were specified by different participants. The participants stated various challenges to teach SPs both in pre- and post-interviews. Safety, time, physical conditions, and materials and equipment were the ones that were discussed mostly both in pre- and post-interviews. Others are emphasized by 1 or 2 participants. The

following quotation is an example of an interviewee's explanation for challenges to teaching scientific practices during pre-interviews:

Especially the time of observation can be very long during physics and biology experiments. The students can be bored and distracted because of this long observation time. Crowded classrooms can be another problem.

This pre-service science teacher's emphasis on time of activities is coded as 'time' and crowded classrooms as 'physical conditions'. Another example of another interviewee's explanation during pre-interviews is presented below:

The students cannot stay quiet. Laboratories are generally constructed vertically, rather than horizontally. So, you cannot see what the students in the back are doing. They don't participate to the lesson. They are usually not interested. They may even sleep in the back. They are far from the eyesight of the teacher. Using lab equipment may be dangerous. Using lab coats and gloves may be another problem because the students may forget to bring them to lab. Students cannot understand the experiments that are conducted in recipe-like manner. If the experiment is too long the students may be bored and unaware of what they do.

This interviewee's identification of students' not staying quiet, participation and interest is coded as 'keeping students' attention', construction of labs are classified in the 'physical conditions' code, experiments conducted in recipe-like manner is coded as 'cookbook activities', danger of using lab equipment is coded as 'safety' and long experiments is coded as 'time'. One of the interviewees' explanations were different before and after the intervention. She listed different challenges, such as keeping students' attention, physical conditions, and materials and equipment during pre-interview.

Yes, well... Some students may be unwilling to listen to the lesson. Ehm... We need to attract their attention. Some students may be very active... I don't know... It depends on student profile... The school's resources may not be sufficient. Materials may be insufficient.

During the post-interview, the same participant claimed that she won't encounter any challenges to teaching SPs. Her explanation is as follows:

It's up to the child but children finds have fun during activities. I don't think I will face any challenges in teaching them.

It can be inferred that this pre-service science teacher's self-efficacy belief toward teaching SPs improved after the sessions. However, this situation cannot be generalized for the other interviewees as they listed various challenges both before and after the intervention. None of the participants talked about 'modeling' as a challenge to teaching SPs. However, one of them emphasized it during post-interview:

The teachers mostly hesitate to teach modeling in lessons. We mostly focus on activities. Modelling is usually neglected. This is a challenge.

This explanation can also be regarded as the positive effect of this intervention. After the intervention, at least one pre-service teacher became aware of modeling being neglected in science lessons. Apart from this result, the participants' explanations during both pre- and post-interviews showed no significant difference in their responses. It can be inferred that the intervention seems to have not had an impact on participants' perception of challenges to teaching SPs.

### Cases of pre-service teachers

In this section, we focus on 3 cases selected among 11 participants who participated in the first study. The aim is to describe 3 cases' perceptions of SPs in more detail and address the changes in their perceptions after the intervention. In order to select the cases, the improvement levels in the cases' perceptions of SPs was used as criteria by considering their perceptions before and after the intervention. These levels are a lot of improvement (Case 1), some improvement (Case 2), and minimal improvement (Case 3). The cases were varied in terms of their gender. Case 1 was male; and Cases 2 and 3 were females. They were third year pre-service science teachers and completed the similar pedagogical courses such as introduction to education, educational psychology, and principles & methods of instruction.

### Case 1: Good improvement

Case 1 classified scientific practices as experiment and observation in the pre-interview. Thus he focused only activities which is a component of scientific practices. However, in the post-interview, he addressed the experimental procedure by adding other components like data and certification. For example, he said that “During experiments, we construct hypotheses. We do somethings to prove them. We make measurements, we record the data. Finally, we show our results to the others to take their approval or not”.

Regarding the basic features of SPs, in the pre-interview, Case 1 said that “there is a relationship between asking questions and discussion.” He explained that “when you ask questions you start a discussion about the question. During this discussion, you provide some evidence to transfer the knowledge in a concrete way. This is how the relationship between these scientific practices is”. However, post interview data show that Case 1 basically addressed the circle of the BRH. For example, he mentioned supported and unsupported arguments, receiving other people’s ideas, and goals of science. Thus, he started to think about the features of science and scientific practices from a wider perspective.

In the pre-interview, Case 1 claimed that there are differences in different domain of science in terms of research field, equipment used, application, methods and subjects. Regarding the difference between science and social sciences he said that the labs are used in science while in social sciences observation is used to gather data. In his post interview, he again mentioned about these differences and mostly mentioned about the difference between literature as a social science and science. An excerpt from his explanation related to literature as a social science is given below:

Literature is a domain of science as well because it aims to help the people to develop. Physics, chemistry and biology are in the laboratories. Actually, I am not sure whether there is a literature science or not. I think, science generally make contributions to the development of the people and make the life easy for the people. So, there are books, poems, articles, etc. in the literature. All these things are carried out to share somethings with the people. That is why literature is a domain of science as well.

For the theme of application of SPs in curriculum and/or schools, in the pre-interview, the Case 1 explained experiments as a scientific practice in curriculum and science classrooms. According to him, in science curriculum, experiments are covered, however, in science classrooms these experiments are rarely used. He also mentioned the importance of experiments in science classrooms. For example, he said that

In science lessons, experiments should be conducted thus students can be more active in classroom. Instead of demonstrations, students should carry out the experiments themselves. Thus they would have experience by doing, trying and seeing... By using experiments in classrooms, teachers would present more concrete and efficient evidence to students.

In the post interview, he focused on other scientific practices such as observation and classification beside experiments. He also mentioned that all of them should in each level like primary, elementary, secondary and college in schools. An excerpt from his post-interview is presented below:

...for example, in primary schools observation should be used in science classrooms. We can take students to the nature and show the colors and variability of animals and plants to them. After making observations, they can design experiments, construct hypotheses, ask questions. In secondary school, different and more complex instructional methods can be used. The students should lead the experiments at this level.

Related to the “challenges to teaching SPs” theme, Case 1 mentioned similar challenges such as safety issues, lack of materials in both pre and post interview. In his post interview, he also added his thoughts related to attitudes of students, teachers and parents.

...There are many teachers who do not like and interested in their lessons. If a teacher does not like his/her lesson, s/he cannot transmit a positive energy to students. Another challenge is students’ attitudes towards science lessons. In Turkey, students might follow limited developments in Turkey. Here, the reason may be attitudes of their parents. If parents have negative attitudes toward science, this will affect students’ positive feelings related to science lessons.

Overall, it can be concluded that Case 1's perceptions of scientific practices improved. Although before the intervention he only mentioned activities such as observation and experiment as scientific practices, he started to perceive data, measurement and certification as scientific practices too after the intervention. In addition, he used many components of BRH to explain scientific practices after the intervention.

### *Case 2: Average improvement*

While Case 2 classified scientific practices only as experiments, observations, sharing the results with the people and classification in the pre-interview, she also mentioned real world, modeling, constructing hypotheses, explanation and communication as scientific practices in the post-interview. As the features of SPs, Case 2 think that scientific practices are measurable, applicable and observable in the pre-interview. She also mentioned that the aims of scientific practices.

...all scientific practices are carried out in order to explain some things, to learn unknown things, to give some answers to people's questions about the world in which we live, to be useful for people and not to give any harm to them. In addition, they are carried out because of curiosity...

In the post interview, she again mentioned curiosity. Furthermore, she talked about communication between scientists with the aim of sharing their investigations and about ethical issues in science. For example, she said that:

...for example when a research about cloning is conducted, people reacts against this type of research and actually they are rightful. Or in my opinion, related to the research on nuclear energy, people need to be relaxed because they may be anxious about these issues. They may have doubts about the possibility of using these things as weapons. So, ethics does not seem to be a part of science. But in fact, it is a part of science.

Regarding domain-specificity, the ideas of Case 2 mostly focused on the difference between social sciences and natural sciences, and difference among chemistry, biology and physics both in pre- and post-interview. She claims that while natural sciences deal

with the nature, social sciences deal with the people, that is to say, they are different in terms of the subjects. She also mentioned about the differences in applications, differences in error rate, the certainty in mathematics. Related to the difference between physics and biology, an excerpt from her interview is given below:

In biology, there is mostly modelling. However, in physics there is mostly experiment and observation parts when compared to other domains of science. For example, evolution in biology is based on modelling. Here there is no chance to make experiments related to this topic. But in physics, scientists can conduct the experiments about their research topics...

Case 2 mentioned giving examples, making observations, and conducting experiments as the applications of SPs in curriculum and schools in her pre-interview. She also shared some ideas related to the need of talking about scientists' lives in science classes. She thinks that teachers should consider the ways that are affected in taking students' attention in science classes. For example, she said that:

In my opinion, to mention about scientists' lives in science classes is important. In which conditions are they doing those experiments? I think, these issues would promote students because there are people who were successful even their educational background was not so good. To hear about them would promote and encourage students about making science...

In her post interview, she mainly talked about the problems related to the applications of SPs in curriculum and schools. She mentioned that there are problems about giving feedback about experiments and evaluating them. She also addressed that explanations, connections between the concepts and real world examples in textbooks were not sufficient. As the challenges to teaching of SPs, the Case 2 focused the same issues like crowded classrooms, limited time to teach SPs, lack of materials and assessment problems in both pre and post interview. In summary, Case 2 showed some improvement after the intervention but there was nothing particularly striking about her progress.

### Case 3: Limited improvement

Case 3 classified scientific practices as experiments, observation, analyzing data and interpreting results in the pre-interview. Then, in the post interview, she also mentioned real world in addition to scientific practices that she mentioned in the pre-interview. As features of SPs, she mentioned a step-by-step procedure in both pre and post interview. She said that

...There are steps to be followed. The first step is determining the problem. The second step is collecting and recording data. There are variables, and control group in this procedure. At the end of the procedure a conclusion should be arrived. All these steps are related to each other. Without each of them, it is not possible to continue with the next one. We can think them as parts of a pyramid.

Her emphasis of steps even after the intervention suggests that she has not changed her mind about the non-linear nature of scientific practices. She mentioned that scientific practices differed based on the domains of science in the pre-interview. For example, she said that while there are mostly experiments in chemistry, observation is mainly used in physics. In addition, she addressed there are differences between different domains of science in terms of goals and methods. In the post interview, she focused on the differences between social sciences and natural sciences. As an opposite view to her initial ideas, she mentioned chemistry and physics are actually similar in terms of using experiments, numerical data, and manipulation.

Related to applications of SPs in curriculum and schools, Case 3 mentioned conducting experiments in the laboratories in both interviews. She addressed the importance of using convenient experiments and observations in terms of students' cognitive levels. Moreover, she mentioned that teachers can also use these activities considering real world as an application of scientific practices. As the challenges to teaching of SPs, Case 3 mainly talked about the challenges during conducting experiments in the laboratories. In the pre-interview, she said that:

Some experiments can be dangerous. The teacher should be careful about dangerous experiments. The teacher's role is so important here. S/he should guide students related to the experiments. If the students

cannot succeed the experiments, they may develop some negative attitudes towards science lessons. Moreover, the experiments should not be like a cookbook. The students should know what they are doing, why they are doing...

In both interviews, she mentioned safety and classroom management issues during conducting the experiments in the laboratories. Thus, she emphasized the role of teacher as a guide to handle the problems and as an instructor to keep the students' interest high.

It is interesting to note that all three participants referred to physics, chemistry, and biology in both interviews. However, none of them mentioned geology or environmental science, although the examples and activities in the workshops and LPs included these topics. Although there is some variation in terms of improvement to their perceptions of scientific practices, the participants showed a more holistic understanding of the components of SPs, basic features of SPs, domain specificity of SPs, SPs to be taught, applications of SPs in the curriculum and schools, and challenges in teaching SPs. All these aspects are crucial because science teachers are responsible for selecting the necessary components of SPs to be included in each science lesson and for teaching these practices, as well as the basic features and domain-specificity of SPs, to their students. They also need to have knowledge about the applications of these practices in the curriculum and in schools and to be aware of the challenges of teaching SPs so that they can find different ways to teach them.

In this paper, we focused on the integration of scientific practices in science teacher education. By using a theoretical heuristic of scientific practices based on the work of Erduran and Dagher (2014a), we illustrated how a theoretical models may potentially be transformed for practical utility in science teachers' training. The empirical study illustrated the opportunities as well as the challenges of infusing epistemic perspectives in teacher education. Pre-service science teachers' perceptions of scientific practices before and after the intervention suggest that the training might have had some impact on how they understand scientific practices. For example, while none of the interviewees talked about 'prediction' and 'explanation' before the intervention, the post interviews included references to these aspects of scientific practices.

The results indicate that the pre-service science teachers considered science disciplines in the category of physics, chemistry, and biology. They did not seem to consider geology and environmental science as separate scientific disciplines. This finding is consistent with the results of another study, which found that Czech teachers' perceptions of geography and geography education are relatively narrow and that a large group of pre-service geography teachers have a fact-oriented, non-relational conception of geography and geography education (Knetcht et al., 2000). These findings point to the need for discussion and emphasis on different disciplines in teacher education programmes. However, the paucity of research studies examining pre-service and in-service science teachers' understanding of different science disciplines also highlights the need for further research into pre-service and in-service teachers' understanding of different science disciplines.

The impact of the intervention, particularly in terms of thinking about scientific practices in holistic terms can be attributed to the use of BRH in the workshops. As a visual tool, BRH guided much of what was done in the workshops with very explicit reference to it in not only understanding aspects of scientific practices but also in integrating them into lesson planning. The combination of theoretical reflection and practical adaptation might have contributed to the enhancement of participants' perceptions. Although "scientific practices" as a construct have been advocated in educational policy (e.g., Achieve Inc., 2013) as well as academically within philosophy of science (e.g., Longino, 2022), there is still much scope for providing evidence of its effective incorporation in teacher preparation courses. Hence, the study has implications for the preparation of science teachers which have been a concern for educators for some time (Cochran-Smith 2004). Future studies may focus on quantitative methodologies where the approaches presented in the paper may be scaled up to more courses and larger cohorts of pre-service teachers in order to provide a measure of the impact of the strategies presented in the paper.

## APPENDICES

### Interview Questions

- What comes to your mind when I say scientific practices? Could you give an example?
- What do you think are the basic features/properties of the scientific practices?
- How do you see the relationships and connections between different features of scientific practices?
- Do you think all sciences have the same scientific practices or are there any differences in sciences in terms of the practices they involve? Explain your reason by giving an example.
- Which scientific practices do you think we should teach students in primary/secondary schools/science lessons?
- Do you think that scientific practices are taught in everyday schools? Do you think scientific practices are part of the science curriculum? Which ones?
- Which teaching methods/techniques/activities do you think can engage students in scientific practices?
- Do you think that there are challenges to teaching scientific practices in science lessons? In what sense?

## REFERENCES

- AAAS. (1989). *Science for all Americans*. American Association for the Advancement of Science.
- Akbayrak, M. and Kaya, E. (2020). Fifth-grade students' understanding of social-institutional aspects of science, *International Journal of Science Education*, 42 :11, 1834–1861, <https://www.doi.org/10.1080/09500693.2020.1790054>.
- Akgun, S. and Kaya, E. (2020). How do university students perceive the nature of science? *Science & Education*, 29, 299–330.
- Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, 13(1), 1–12.
- Barak, M. (2023). Family Resemblance Approach in Science Education. *Sci & Educ* 32, 1221–1225. <https://doi.org/10.1007/s11191-023-00456-1>
- Boujaoude, S., Dagher, Z. R., and Refai, S. (2017). The portrayal of nature of science in Lebanese 9th grade science textbooks. In C. V. McDonald & F. Abd-El-Khalick (Eds.), *Representations of nature of science in school science textbooks: A global perspective* (pp. 79–97). Routledge.

- Bybee, R.W. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education*, 25(2), 211–221. <https://www.doi.org/10.1007/s10972-014-9381-4>.
- Cheung, K. K. C. (2020). Exploring the inclusion of nature of science in biology curriculum and high-stakes assessments in Hong Kong. *Science & Education*, 29(3), 491–512. <https://www.doi.org/10.1007/s11191-020-00113-x>.
- Cochran-Smith, M. (2004). The problem of teacher education. *Journal of Teacher Education*, 55(4), 295–299. <https://www.doi.org/10.1177/0022487104268057>.
- Dagher, Z., and Erduran, S. (2023). To FRA or not to FRA: What is the question for science education?. *Sci & Educ* 32, 1247–1264. <https://doi.org/10.1007/s11191-023-00425-8>
- Driver, R., Leach, J., Millar, R. and Scott, P. (1996). *Young people's images of science*. Open University Press.
- Duschl, R.A. & Bybee, R.W. (2014). Planning and carrying out investigations: an entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Education*, 1(1), 12. <https://www.doi.org/10.1186/s40594-014-0012-6>.
- Erduran, S. and Dagher, Z. (2014a). *Reconceptualizing the nature of science for science education: Scientific knowledge, practices and other family categories*. Springer.
- Erduran, S. and Dagher, Z. (2014b). Regaining focus in Irish junior cycle science: Potential new directions for curriculum and assessment development on nature of science. *Irish Educational Studies*, 33(4), 335–350.
- Grandy, R. and Duschl, R. (2008). Consensus: Expanding the scientific method and school science. In R. Duschl and R. Grandy (Eds.), *Teaching scientific inquiry: Recommendations for research and implementation* (pp. 304–325). Sense Publishers.
- Hogan, K. and Maglienti, M. (2001). Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions. *Journal of Research in Science Teaching*, 38(6), 663–687.
- Irzik, G. and Nola, R. (2014). New directions for nature of science research. In M. Matthews, *International handbook of research in history, philosophy and science teaching* (pp. 999-1021). Springer.
- Jorde, D. and Dillon, J. (Eds.) (2012). *World of science education: Europe*. Sense Publishers.
- Kaya, E., Erduran, S., Aksoz, B. and Akgun, S. (2019). Reconceptualised Family Resemblance Approach to Nature of Science in pre-service science teacher education. *International Journal of Science Education*, 41(1), pp. 21–47, <https://www.doi.org/10.1080/09500693.2018.1529447>.
- Knecht, P., Spurná, M. and Svobodová, H. (2020). Czech secondary pre-service teachers' conceptions of geography. *Journal of Geography in Higher education*, 44(3), 458–473. <https://www.doi.org/10.1080/03098265.2020.1712687>.
- Latour, B. (1987). *Science in action*. Harvard University Press.
- Latour, B. (1989). *La science en action*. La Découverte.
- Lemke, J. L. (2004). The literacies of science. In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction* (pp. 33–47). International Reading Association.
- Longino, H. E. (2002). *The fate of knowledge*. Princeton University Press.
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.
- Nersessian, NJ. (2008). *Creating scientific concepts*. The MIT Press.
- NGSS Lead States. (2013) Next generation science standards: For states, by states. Appendix H. Retrieved from <http://www.nextgenscience.org/next-generation-science-standards>.
- Park, W., Yang, S. and Song, J. (2020). Eliciting students' understanding of nature of science with text-based tasks: Insights from new Korean high school textbooks. *International Journal of Science Education*, 42(3), 426–450.
- Petersen, I., Herzog, S., Bath, C. and FleiBner, A. (2020). Contextualisation of factual knowledge in genetics: a pre- and post-survey of undergraduates' understanding of the nature of science. *Interdisciplinary Journal of Environmental and Science Education*, 16(2). <https://doi.org/10.29333/ijese/7816>.
- Schwab, J. (1964). Structure of the disciplines. In G. W. Ford and L. Pugno (Eds.), *The structure of knowledge and the curriculum*. Rand McNally.
- Wickman, PO. (2004). The practical epistemologies of the classroom: a study of laboratory work. *Science Education*, 88, 325–344.
- Yeh, Y., Erduran, S. and Hsu, Y. S. (2019). Investigating coherence on nature of science in the science curriculum documents: Taiwan as a case study. *Science & Education*, 28(3–5), 291–310. <https://doi.org/10.1007/s11191-019-00053-1>.
- Zeidler, D. L., Walker, K.A., Ackett, W. A. and Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, 86(3), 343–367.
- Zemal-Saul, C. (2009). Learning to teach elementary school science as argument. *Science Education*, 93(4), 687–719.