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Research in Science Education

ISSN 0157-244X

Res Sci Educ

DOI 10.1007/s11165-018-9773-0



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Drawing Nature of Science in Pre-service Science Teacher Education: Epistemic Insight Through Visual Representations

Sibel Erduran¹  · Ebru Kaya²

Published online: 06 November 2018
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Abstract

Developing pre-service science teachers' epistemic insight remains a challenge, despite decades of research in related bodies of work such as the nature of science (NOS) in science education. While there may be numerous aspects to this problem, one critical element is that the NOS is a meta-concept that demands higher-order cognitive skills. One possible strategy to facilitate pre-service teachers' understanding of epistemic aspects of science is visualisation. Visual representations of objects and processes can be tools for developing and monitoring understanding. Although the NOS and visualisation literatures have been studied extensively, the intersection of these bodies of literatures has been minimal. Incorporating visual tools on the NOS in teacher education is likely to facilitate teachers' learning, eventually impacting their students' learning of the NOS. The objective of this paper is to illustrate how the visual tools of scientific knowledge and practices aspects of the NOS can be integrated in science teacher education in order to develop pre-service teachers' epistemic insight. The paper presents an empirical study that incorporated visual tools about the NOS in primary science teacher education. Data on 14 pre-service teachers' are presented along with in-depth case studies of 3 pre-service teachers illustrating the influence of the teacher education intervention. The qualitative analysis of visual representations before and after the intervention as well as verbal data suggests that there was improvement in pre-service teachers' perceptions of the NOS. Implications for future research on visualisation of the NOS are discussed.

Keywords Nature of science · Teacher education · Visualisation

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Introduction

The nature of science (NOS) is a significant area of research in science education (Erduran 2017; Erduran and Dagher 2014; Kaya and Erduran 2016; Lederman 2007; McComas and Olson 1998; Smith et al. 1997). In an early account of NOS, Driver et al. (1996) highlighted five potential benefits of students' learning about the NOS, namely that understanding of the NOS helps students to (a) understand the process of science, (b) make informed decisions on socio-scientific issues, (c) appreciate science as a pivotal element of contemporary culture, (d) be more aware of the norms of the scientific community, and (e) learn science content with more depth. There are different characterisations of the NOS in science education (e.g. Allchin 2011; Matthews 2012). A common feature of all is that they consider the epistemic aspects of science. For example, Erduran and Dagher (2014) characterise the NOS as a cognitive, epistemic, and social institutional system. The system has various components such as aims and values, practices, methods and methodological rules, knowledge, social ethos, social values, professional activities, social certification and dissemination, social organisations and interactions, financial systems and political power structures.

Teaching and learning of the NOS can contribute to epistemic insight. Epistemic insight concerns 'knowledge about knowledge' (Billingsley and Ramos 2017). Knowing *how* and *why* we know in science as well as *what* we know are important in recognising the power and limitations of science. Science has had a tradition of offering knowledge that helps explain and predict physical and natural phenomena. While some knowledge is in the form of theories, such as the atomic theory, others might be best characterised as models and laws, for instance molecular models and the law of conservation of mass. There is vast amount of research literature on each of these knowledge forms (e.g. Cartwright 1983; Christie and Christie 2003). Scientists produce scientific knowledge by engaging in a set of practices such as gathering and analysing data. Knowledge production in science involves observation, analysis and testing of phenomena within the communication framework of a particular research community with its accepted methodology. Scientific practices such as experimentation, observation and classification all contribute to how scientists generate data (Erduran and Dagher 2014). Scientists use such data to build models which can be used to explain and predict phenomena (Giere 1992).

Despite the large volume of work on the NOS, developing pre-service science teachers' (PSTs') epistemic insight remains a challenge. PSTs often do not get direct exposure to the epistemic aims and values of science (e.g. Kelly and Erduran 2018). While there may be numerous aspects to this problem, one critical element is that the NOS is a meta-concept that demands higher-order thinking skills (e.g. Erduran and Kaya *in press*). Recent accounts of metacognition research in the context of science education include work by Zohar and Ben-David (2008) who discuss meta-strategic knowledge as a sub-component of metacognition. Meta-strategic knowledge is the 'thinking behind the thinking' rather than the 'thinking behind the doing'. Visualisation is one possible strategy to facilitate PSTs' understanding of what scientific knowledge and practices are about, thereby developing their epistemic insight. Furthermore, visual representations can be tools for developing and monitoring understanding (Gilbert et al. 2008). Although the NOS and visualisation literatures have been studied extensively, the intersection of these bodies of literatures has been minimal.

In this paper, we explore the role of visualisation in order to highlight how it can be related to the NOS in science education and how it can be incorporated into PSTs' learning. Although there are numerous accounts of the NOS in science education (e.g. Lederman 2007), the only account that inherently capitalises on the use of visual representations in the NOS is provided by Erduran and Dagher (2014). In other words, various accounts of the NOS are primarily focused on textual tenets of what NOS is about and how some declarative and text-based formulations can be applied in

science education (e.g. Allchin 2011). Erduran and Dagher (2014) on the other hand, produced a set of visual representations derived from review of literature from philosophy of science. These visual tools are meant not only to summarise some key ideas on the NOS but also to have some educational utility, as they will be described in the rest of the paper. Following a theoretical account on visualisation and the NOS, we present a primary science teacher education project that incorporated visual tools with the aim of facilitating PSTs' understanding of the NOS. Qualitative analysis of empirical evidence from PSTs' drawings and interviews is used to present the outcomes of the teacher education intervention.

Visualisation in Science Education

Although the intersection of visualisation with the NOS literature has been minimal, the role of visualisation has been highlighted extensively in the broader science education literature (e.g. Dori et al. 2003; Gilbert et al. 2008). A related area of research concerns representational reasoning (Tytler et al. 2013). Engagement with multiple representations including visual data in science textbooks is an important part of teachers' knowledge of science (Eilam and Gilbert 2014). Waldrip et al. (2010) point out that 'representations can be used as tools for initial, speculative thinking, as in constructing a diagram or model to imagine how a process might work, or find a possible explanation, or to see if a verbal explanation makes sense when re-represented in 2D or 3D' (p.75). Tippet (2016) examined the trends of representational uses in science instruction and reported that both interpreting and constructing representations can provide a better understanding of science concepts.

Eilam et al. (2014) investigated science and mathematics teachers from diverse backgrounds as the teachers produced generated visual representations based on textual data. The findings indicated that teachers had difficulty producing visual representations which exist in two ontological forms (Gilbert 2005). The first of these is as internal representations which are the personal mentally constructions of an individual, typically referred to as 'mental images'. The second is as external representations which are open to inspection by others. Visual representations of how science works enable teachers and students to make connections between their own experience and scientific concepts and therefore gain epistemic insight into abstract ideas about science (Duschl and Erduran 1996). Waldrip et al. (2010) argued that student-generated representations illustrate the value of non-standard representations in providing a basis for student clarification or understanding. In other words, representations can be useful tools in learning and understanding. Student representations can also provide a visible and concrete means for teachers to monitor the students' progress in their learning. An analogy can be drawn with PSTs' learning in terms of how their drawings about how science works can be vehicles for learning, and how teacher educators can potentially monitor their progress. What visual representations of the NOS, then, can be considered for science teacher education? How can PSTs' visual representations be used to investigate their understanding of the NOS?

Visualising the Nature of Science

Given the focus of epistemic insight in this paper, we focus on Erduran and Dagher's (2014) categories of scientific knowledge and practices as aspects of the NOS. This is because *scientific knowledge* is directly relevant to epistemic issues in science given it is about forms of knowledge and growth of knowledge, and *scientific practices* are about epistemic processes such as

experimentation and modelling. While *scientific knowledge* demonstrates the epistemic outcomes of science, *scientific practices* illustrate the mediation of epistemic processes that lead to scientific knowledge. Together, these categories provide a complementary account of how scientific knowledge and practices work together, and they can potentially contribute to teachers' and students' epistemic insight. We review each category including the proposed visual tools intended to provide a practical and accessible summary of some rather dense and abstract concepts.

Visualising Scientific Knowledge

Erduran and Dagher (2014) argued that theories, laws and models (TLM) are different forms of scientific knowledge that work together to produce scientific knowledge. They represented TLM and growth in TLM visually, summarising some important aspects of scientific knowledge such as accumulation and growth in scientific knowledge. In Fig. 1, the boxes represent the progressive accumulation in theories, laws and models as new evidence is gathered. The arrows represent coordinated growth in time leading to scientific understanding. The entire plane is about a particular framework within which scientists operate at a particular point in time. If new evidence emerges that contradict TLM, the entire plane might be started again in the context of a *paradigm* shift. Thus, TLM is a *meta-tool* that highlights the significance of understanding what constitutes scientific knowledge, without which teachers and students would not get a sense of the different forms of knowledge. Visual heuristics would potentially give teachers and students a sense of the progression of ideas, how ideas change over time and how ideas can at times be abandoned altogether and replaced by new ones. In short, such tools can help understanding of different knowledge forms in science and how these knowledge forms work together to produce understanding in science over time.

Erduran (2014) proposed the example of the atom to illustrate how TLM works. The structure of matter is explained with different types of knowledge: atomic theory, the periodic law of elements and molecular models. These forms of knowledge need to be consistent with each other, and altogether they point to the structure of the atom. While all science disciplines might share TLM, the precise nature of TLM might be specific to a particular discipline. For example, *law* might have a specific meaning in chemistry as compared to physics. In physics, laws can be axiomatized in mathematical formulas, whereas in chemistry, some laws can be approximations not necessarily reducible to mathematical formulas (e.g. Christie and Christie 2003). If a particular TLM at a certain point in time cannot explain a phenomenon, a paradigm

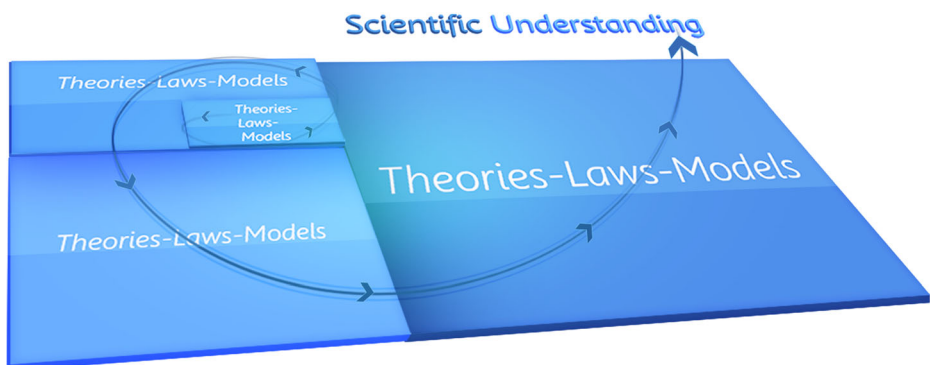


Fig. 1 TLM, growth of scientific knowledge and scientific understanding (from Erduran and Dagher 2014, p. 115)

shift might occur. In chemistry, for example, the shift to Lavoisier's theory of oxygen from the phlogiston theory is an example of a paradigm shift (Erduran 2014). TLM brings coherence to the various forms of scientific knowledge by illustrating how they are related and also accounting for how TLM changes as evidence accumulates. The visual tool proposed by Erduran and Dagher (2014) thus implicitly captures some rather complex concepts such as *theory, law, model, paradigm* and *paradigm shift* in a relatively simple heuristic that can help teaching and learning.

Visualising Scientific Practices

Scientific knowledge construction happens through a set of epistemic, cognitive and social practices such as reasoning, argumentation and social certification of ideas. Erduran and Dagher (2014) produced a visual tool referred to as the *Benzene Ring Heuristic* (BRH) to summarise some key scientific practices (see Fig. 2). BRH uses the analogy of the benzene ring from organic chemistry to summarise scientific practices. Each carbon atom around the ring and the diffuse pi bonds represent the social contexts and practices that apply to all of these aspects. Comparatively, the cognitive, epistemic and social aspects of science are interrelated and influence one another. The ring structure represents the 'cloud' of cognitive and social practices that mediate the epistemic components such as models and explanations.

BRH articulates how scientists use data originating from the real world to generate explanations, predictions and models. In a sense, the heuristic highlights the mechanisms for how the TLM growth occurs. In school science, the activities of experimentation, classification and observation tend to be covered in a disconnected fashion that does not necessarily lead to modelling. The heuristic aims to foster a coordinated approach to scientific practices. For example, chemists debate what data to use to generate models and how. While the visual heuristic presented in Fig. 1 emphasises the components of scientific knowledge and its growth, Fig. 2 illustrates some of the mechanisms and interactions that mediate how scientific knowledge is produced.

The brief review of scientific knowledge and scientific practices from Erduran and Dagher's (2014) account illustrates the potential of visual tools in communicating some fairly complex ideas about the NOS. In the rest of this paper, we illustrate how the theoretical characterisation of scientific knowledge and practices from Erduran and Dagher's (2014) have

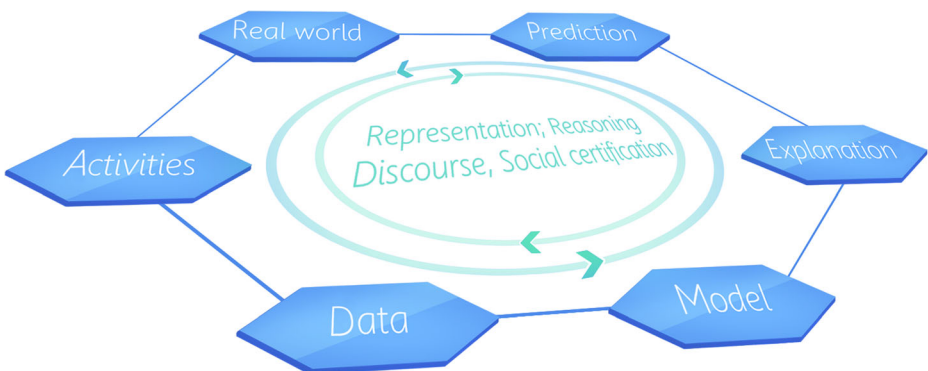


Fig. 2 Benzene Ring Heuristic of scientific practices (from Erduran and Dagher 2014, p. 82)

been adopted for use in science teacher education as part of an intervention study in pre-service science teacher education. The ultimate purpose of the intervention was to explore how PSTs' understanding of the NOS can be improved. This line of work is consistent with other approaches that have aimed to develop teachers' epistemic insight through teacher education (e.g. Billingsley and Ramos 2017).

Methodology

The section outlines the research questions and the methods that guided the study. A funded project was conducted in the context of a primary science teacher education programme at an English-medium university in Turkey (e.g. Kaya et al. [in press](#)). A total of 14 female PSTs who were seniors in a Master's level course participated in the study. We illustrate the entire cohort's progress as evidenced by their drawings, and focus on 3 PSTs to provide an in-depth coverage on how PSTs' understanding of scientific knowledge and scientific practices can be improved through visual tools.

Research Questions

The study was guided by the following research questions:

1. What is the nature of PSTs' visual representations of scientific knowledge and practices?
2. How does the use of visual tools on scientific knowledge and practices in teacher education influence PSTs' visual representations of scientific knowledge and practices?

Teacher Education Project

The teacher education project included 11 sessions, each session lasting for 3 h. The sessions were dedicated to the aims and values of science, scientific practices, scientific methods and methodological rules, scientific knowledge and social context of science. Each category was covered in 2 sessions. In the workshop focusing on scientific knowledge, PSTs engaged in a task that asked them to produce examples of theories, laws and models from any domain of science. For example, for chemistry, they worked on the topic of gases, and wrote kinetic energy theory, gases laws and the models contributing to the understanding of particulate nature of matter. Each group then evaluated another group's example, reinforcing their understanding with further examples. In the second part of the activity, the PSTs researched examples of paradigm shifts where theories, laws and models would now be considered in terms of how they change over time. The group then produced a poster to communicate their examples about paradigm shifts. In the workshop focusing on scientific practices, PSTs were introduced to the Benzene Ring Heuristic (BRH) which was exemplified by the use of acid-base chemistry. Different topics were used intentionally to ensure that PSTs could see the applications of the abstract ideas about scientific knowledge and practices. Each aspect of the heuristic was reviewed and PSTs were tasked with producing examples in their groups to visually represent how they understand scientific practices. The visual tools from Figs. 2 and 3 were used in the workshops. For example BRH was

research for some time (e.g. Yin 1994). The data sources include pre- and post-interviews and drawings produced before and after the teacher education sessions.

Research Instruments

The primary sources of data are PSTs' drawings and individual interviews. Before and after the sessions, the PSTs were asked to draw what they understand by scientific knowledge and practices. They were also asked to explain their drawings. There is widespread consensus that the processes of creating and revising visual representations (i.e. drawings) can lead to a deeper understanding of the scientific concepts (Waldrup and Prain 2012). The PSTs were also interviewed individually. The interview aimed to elicit their perceptions and understanding of the nature of scientific knowledge and practices through questions such as "What comes to your mind when you hear scientific knowledge? Why?" Data analysis was qualitative in nature. Qualitative analysis of visual data is an established methodology (Banks 2007; Radley 2010) that can offer insight into participants' understanding. PSTs' drawings were analysed by the authors who were part of the teacher education sessions, and who were familiar with the context. Each author also taught one of the sessions on scientific knowledge and practices. In this way, the authors were able to discuss the drawings and interpret them relative to the goals of the project.

Results

The results of data analysis will be presented in three sections. First, the overall pattern in the PSTs' drawings before and after the teacher education sessions will be presented. For simplicity, we will refer to the teacher education sessions as the *intervention* in the sense that the sessions were intended to have an impact on PSTs' perceptions and understanding. Here, we will discuss the qualitative differences in all 14 PSTs' drawings. Second, we will focus on 3 PSTs who were in a group together to detail, in-depth, how their drawings changed. We will finally supplement the drawings with verbal data from individual interviews conducted with the 3 PSTs.

Trends in PSTs' Pre- and Post-Intervention Visual Representations

The drawings of scientific knowledge and practices from all 14 PSTs before and after the intervention have been qualitatively analysed. The extent of the difference in the quality of the images was noted. The following criteria were used to identify the differences. Where there was a significant difference in terms of the content of the drawing, the change was marked as a big difference. For example, if the PST did not mention scientific knowledge forms as theories, laws and models initially but after the intervention made an explicit reference to them along with other themes from the sessions (such as growth of scientific knowledge), the change was identified as *big*. If there was some incorporation of ideas promoted in the intervention but not a significant difference in the drawings, the image was coded as a *medium* difference. If there was a very minor difference, the change was noted as *small*. If there was practically no difference in the content or quality of the pre- and post-drawings, then the drawings were

identified as having had *no difference*. Figure 3 illustrates examples of each category. As an illustration, the *Big* difference in the scientific knowledge example consists of the following. In the pre-intervention drawing, the PST is referring to some generic science-related vocabulary such as hypothesis, theory and laws. Even though she has mentioned forms of scientific knowledge, her overall orientation in the drawing seems to be about knowledge production through experimentation. In the post-intervention drawing, on the other hand, she is not only referring to the forms of scientific knowledge but also illustrating how scientific knowledge grows.

In terms of the scientific knowledge category, all 14 PSTs' drawings exhibited a large difference. With respect to the scientific practices category, 7 PSTs exhibited a large difference, 3 a medium difference, 3 a small difference and 1 no difference. The largest difference was in the scientific knowledge category where all participants had a big difference in the quality of the pre- and post-images and descriptions. The big difference in knowledge category could be due to a rare emphasis of the key issues about knowledge (such as differentiation of knowledge forms as theories, laws and models) in the participants' education before the intervention. The same students had taken another class where they covered the BRH tool for scientific practice, which explains why they had prior knowledge and why the representations of some PSTs were the same before and after the intervention. However, the variation in the quality of the representations suggests that it was either difficult for PSTs to express scientific practices visually or they had a hard time understanding scientific practices.

Case Studies of Pre-service Teachers' Visual Representations

In this section, we summarise the visual representations of 3 PSTs before and after the intervention. In each case, we illustrate what their drawings included and how they shifted following the teacher education sessions. The criteria for evaluating the extent of difference were related to the goals of the particular workshop. For instance, the key emphasis in the knowledge session was on theories, laws and models (TLM) as the forms of knowledge and how they work together in knowledge growth. Hence, for the *scientific knowledge* category, if there was a big difference in how the PSTs drew prior to the intervention without any reference to TLM, followed by a major incorporation of the TLM ideas and models of knowledge growth after the intervention, then we would code this instance as having had a big difference.

Case 1

Before the intervention, when asked to draw a picture in order to represent scientific knowledge, PST1 referred to DNA and virus with some visual representations (Fig. 4). She further explained that "she wanted to give an example from medicine," to justify her drawing. Her representation of scientific knowledge after the intervention consisted of a "bird bath" illustrating flow of water across different levels. The figure illustrates scientific knowledge in terms of TLM and the PST1 specifically linked the drawing to what "we did in class." She further gave the example of the atomic models and used the words "bigger and bigger" to communicate growth of knowledge. Here, the switch from particular scientific concepts such as DNA and virus to an analogy of a bird bath to represent growth of knowledge illustrates a shift in how PST1 viewed the task initially in terms of science concepts and in terms of epistemic aspects of

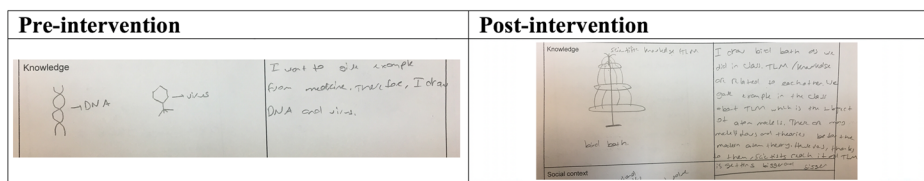


Fig. 4 PST1’s pre- and post-intervention representations of scientific knowledge

knowledge following the teacher education intervention. The adoption of the TLM terminology is directly related to what was covered in the workshops.

Before the intervention, in order to represent scientific practices, PST1 referred to pills, serum and benzanol with their visual representations (Fig. 5). PST1 explained that she gave medical practices as an example. She further stated that “also, chemistry has got implementations on medicine.” In her post-intervention representation, PST1 made reference to real world, explanations, predictions, models, data, activities, representing, reasoning, discourse and social certification visually using a star. She explained that she “draw a star which have 6 ends to represent the relationships of practice.” There was a move from PST1’s initial idea of scientific practices as medical practices to scientific practices as described by some key terms such as explanation and modelling highlighted in the sessions. Her drawing was very similar to the Benzene Ring Heuristic (BRH) to represent scientific practices and the relationships among these practices. While her previous drawing is about examples of chemical materials, her subsequent drawing incorporated an adaptation of the BRH.

Case 2

Before the intervention, PST2 used the words “books”, “experiment” and “internet” with some visuals such as a book, computer, beaker and Erlenmeyer flask to represent scientific knowledge (Fig. 6). She justified her drawing with the words “books”, “technology”, “experiments” and “papers.” In her post-representation, PST2 drew small and big fish and wrote “TLM” on each fish. She also mentioned other TLMs in her drawing and explained that “TLM part is like a waterfall. It is an ever increasing structure and all parts are related to each other.” PST2 illustrated the growth of scientific knowledge by drawing the small and big fish and explaining the growth of knowledge with the analogy of waterfall, whereas her previous drawing is limited to a random set of scientific objects and tools. Furthermore, after the intervention, she made referenced to TLM as a representation of theory, law and model as types of scientific knowledge.

PST2 made a reference to “making experiment” by drawing a person who is doing an experiment to represent scientific practices before the intervention (Fig. 7). She used the words “experiment”, “research” and “using technology” to explain her drawing. She used the words

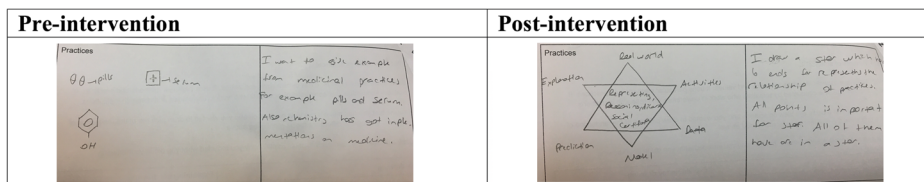


Fig. 5 PST1’s pre- and post-intervention representations of scientific practices

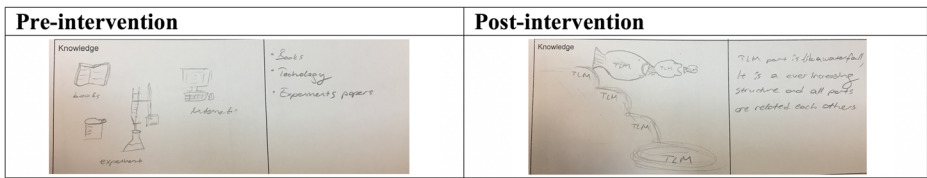


Fig. 6 PST2's pre- and post-intervention representations of scientific knowledge

“experiment” and “technology” to explain her representation of scientific knowledge as well. After the intervention, she wrote model, real world, data, prediction, activities and explanation as scientific practices in her drawing and she stated that “all practices have equal importance.” In her post-intervention representation, she used ball and stick model and put each scientific practice with an equal distance to the centre. Although her initial representation of scientific practices was only experiment, she included the other scientific practices in addition to experiment in her post-representation which is an adaptation of the BRH.

Case 3

PST3 made a reference to “bread” with its visual to represent scientific knowledge before the intervention (Fig. 8). She justified her drawing by stating that “...because bread is necessary and essential for human life. Knowledge is also necessary and essential for science.” Her further explanation is about the similarity of the bread analogy and science concept. She also referred to types of knowledge by using the bread analogy and stated that “we eat not one type of bread like this knowledge is not one type, it can change also.” After the intervention, she did not use any words in her drawing. She drew some circular objects in different sizes that are falling down on a sloped surface. In her explanation, PST3 again referred to the necessity of knowledge. Additionally, she referred to theory, law and model as the forms of knowledge. In order to explain her drawing, she stated that “I draw the TLM process like snowball. When the snowball is at the peak of the mountain, it is small, and it grows up like theory, law, model.” While PST3’s previous representation only focused on the necessity of knowledge and knowledge type which is more than one, after the intervention, her visual represented the growth of scientific knowledge and she explained theory, law and model as different types of scientific knowledge. She just mentioned that knowledge is not one type before the intervention, but she could differentiate the types of knowledge in after the intervention.

In order to represent scientific practices, PST3 used the words “How? What? Why?” with a big question mark visual and the word “brain” with the drawing of a brain before the intervention. After the intervention, she made references to real world, data, prediction, explanation, model, activity, representation, reasoning, discourse and social certification in

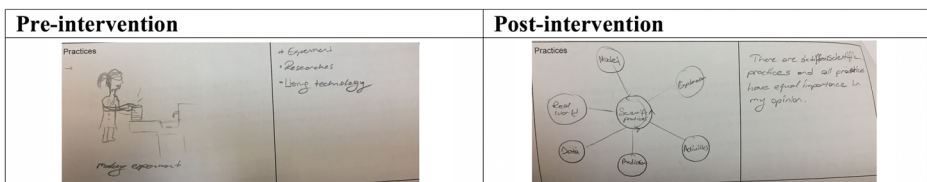


Fig. 7 PST2's pre- and post-intervention representations of scientific practices

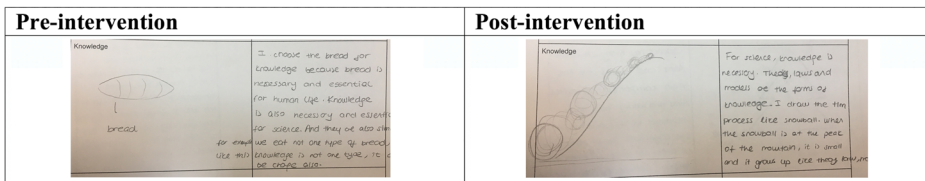


Fig. 8 PST3’s pre- and post-intervention representations of scientific knowledge

her representation of scientific practices. In her justification, she stated that “they have same importance and related concepts so I chose the daisy model. Each leave has same importance for daisy.” While PST3’s initial representation of scientific practices is only about asking questions, after the intervention, she included all scientific practices in a daisy drawing which is an adaptation of the BRH (Fig. 9).

The PSTs used vocabulary to supplement their drawings about scientific knowledge and practices. The trends in the use of vocabulary are consistent with the changes in the nature of the visual representations. One of the trends across the 3 PSTs is that, prior to the intervention, they offered very specific examples of scientific concepts (e.g. DNA, virus), processes (e.g. experiment, questioning) and objects (e.g. books, internet, bread), but after the intervention, they made explicit reference to the terminology that surrounded the visual heuristics used in the workshops (e.g. TLM, prediction, explanation, real world). One interpretation to this observation is that the students are only parroting the terminology that they have learned in the workshops and that they may not necessarily understand what they mean. However, coupled with their use of analogies to interpret the visual heuristics, one possible interpretation is that they have already begun to internalise and personalise the learning about scientific knowledge and practices learned from the workshops by connecting such learning to everyday analogies that they are familiar with.

PSTs’ Perceptions of Scientific Knowledge and Practices

All PSTs shifted in their verbal expression of scientific knowledge and practices. In the pre- and post-intervention interviews, they were asked to state what comes to their mind when they hear “scientific knowledge” and “scientific practices.” PST1 initially talked about scientific knowledge in general terms as follows:

When I hear scientific knowledge, I think of proven knowledge. Like low quality and high quality knowledge. Simple knowledge can be learned by all. More advanced knowledge is about experts’ knowledge. (PST1, pre-interview)

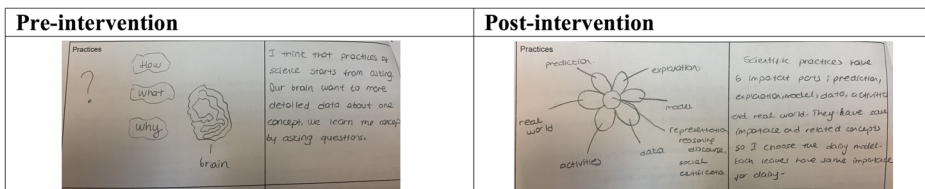


Fig. 9 PST3’s pre- and post-intervention representations of scientific practices

After the intervention, she made more explicit reference to theories, laws and models. Furthermore, she highlighted the importance of interconnections between these forms of knowledge by stating that “these are not separately growing in a stepwise fashion”:

If we take atomic models as an example, like I said before. I think we can teach about how models, theories and laws develop when we teach about scientific knowledge. These are not just separately growing in a stepwise fashion. They contribute to each other and students need to understand that. (PST1, post-interview)

PST3 on the other hand thought of knowledge in terms of different fields of inquiry such as science and mathematics and their sub-fields:

Like certain, true thing. More accurate knowledge. Knowledge types? Maybe like science gets separated, like how there's mathematics, geometry. They are different branches. Like chemistry. Like physical knowledge, they all have different branches (PST3, pre-interview)

In the post-interview, PST3 was quite articulate about her understanding of scientific knowledge. While she repeated aspects of certainty and truth about scientific knowledge, as she had mentioned in the pre-interview, this time, she extended her response to include a reflective account about how she learned new aspects to scientific knowledge:

I think about the most basic thing when I think of scientific knowledge. It's something that's true. In other words, it's been proven through scientific methods through certain practices. It's been proven and the outcome is scientific knowledge. Theories, laws and models are types. I remember when we first talked about this, I didn't know. Nothing like this was taught to us at school. We did learn about theories and laws but models were never mentioned with them. Theories would be proven and become laws, and laws don't change. I realised there is no such thing. There's also models. I never knew this. (PST3, post-interview)

Here, PST3 recognised what was missing in her own learning about scientific knowledge, namely models, and also mentioned the limitations of school science in getting students to learn about scientific knowledge. With respect to PSTs' understanding of scientific practices, there was also a shift. Consider PST1's reference to a particular chemistry example of the boiling and freezing of water and how she thinks of the 'practical' aspects of science:

I think about practical things about science. Like water boils at 100 degrees. When we put salt in it, the boiling point increases. Also like the freezing point is 0 degrees. They put salt on icy streets. I think of such things when I hear scientific practices. (PST1, pre-interview)

This suggests that the word “practices” might present an issue if the students are not familiar with the particular sense of the words “scientific practices” as they are used in science education research as well as curriculum policy. In the post-interview, however, she tried to remember the details of BRH and related scientific practices to a particular example from history of chemistry:

There's data, real world related to data. Was there observation, there's observation. I am trying to think about scientific practices. Like there's observation in the real world and reach scientific knowledge. There's testing procedures. Then modelling all that's been

found. There was another aspect which I don't remember now. In chemistry we can think about Toricelli experiment. He was doing an observation. He is observing the real world. There's a difference in pressure. That's scientific practice. (PST1, post-interview).

While PST1 mentioned most aspects of the BRH in the post-interview, she did not make reference to the social aspects including the social certification or representation embedded in scientific practices. The sense of "practice" as related to everyday practical matters is echoed in PST2's pre-interview:

It could be experiments that you can use in everyday life. Like what children could do in a lesson. They could do chemical experiments, what we can do to protect our environment. Teaching children what goes in which recycling bin. We can raise their awareness about waste. We could design an activity to be mindful about the environment. (PST2, pre-interview)

However, she was able to list the key components of the BRH after the intervention, although, like PST1, she did not make any reference to the social and mediational aspects of scientific practices such as argumentation and representation:

I think about observation when I think about scientific practices. Also experiment, manipulative or non-manipulative kinds. Like experiments with soap or gases. The relationship between pressure and volume. Data collection, experimentation, observation. There's also explanation. There's modeling. (PST2, post-interview)

Similar to PST1 and PST2, PST3 also thought of scientific practices in terms of the practical dimensions, particularly in terms of bridging theory to practice by saying 'making something real from what we imagined':

Scientific practices...Nothing much really. Like an experiment and making something real from what we imagined. Like what you try out at the lab. For example, acid-base reaction and how it always produces neutral salts. (PST3, pre-interview)

Overall, the interview data suggest that all three PSTs showed some progress in terms of their understanding of scientific knowledge and practices although there seemed to be more of a marked progress in their characterisation of scientific knowledge than in scientific practices. It is understandable that all three had interpreted scientific practices in the sense of something 'practical'.

Conclusions and Discussion

This study illustrated how visualisation of aspects of the NOS, namely scientific knowledge and scientific practices, can be incorporated in PST education. An empirical project was described to highlight how some visual heuristics developed by Erduran and Dagher (2014) were adapted for pedagogical purposes and applied in teacher education sessions. All 14 PSTs showed a big difference in their visual representations of scientific knowledge, whereas the pattern was more complex for representations of scientific practices. In relation to the 3 cases of PSTs explored in more detail, before the intervention, the representations of scientific knowledge and scientific practices were based on

specific examples. However, after the intervention, PSTs referred to the concepts related to scientific knowledge and scientific practices covered in the workshops. In their pre- and post-representations, all PSTs used analogies from everyday life to express what they meant by scientific knowledge and practices. The interview data suggest that all three PSTs showed some progress in terms of their understanding of scientific knowledge and practices although there seems to be more of a marked progress in their characterisation of scientific knowledge than of scientific practices.

Evidence suggests some impact on all 3 PSTs although it was not possible to explore any impact on teaching practice. It is anticipated that the meta-tools of TLM and BRH along with the personal interpretations by PSTs through their own visual representations can be used to guide lesson planning. For example, for a particular topic such as acids and bases, BRH can be used to identify components of scientific practices including classification and modelling of acid-base behaviour. TLM and BRH could be used implicitly or explicitly, depending on also other factors such as the age of the students and the cognitive demands of the tasks involved. Further research is needed to investigate how PSTs interpret the meta-tools in their teaching practice. Since the objective of this paper was to contribute to an in-depth understanding of issues related to the use of visual heuristics on the NOS, a significant outcome of the study is that, given the appropriate support with visual tools, PSTs can be guided to make better sense of epistemic perspectives of science. Although the study contributes to the understudied research area of visualisation of the NOS and incorporation of visual tools in teacher education, it has limitations in terms of the sample size of PSTs. Future work could aim for larger-scale teacher education interventions where further trends in PSTs' perceptions and representations can be investigated with larger samples of participants.

Overall, this paper raises questions about what the teaching of the NOS contributes to understanding of how science works in terms of its epistemic dimensions. The frameworks of scientific knowledge and practices reported in the theoretical background of the paper (i.e. TLM and BRH) are, by definition, promoting interconnections between meta-concepts about how science works in terms of knowledge production processes and outcomes. The underlying assumption is that often school science does not enable learners to understand how science generates knowledge and what this knowledge is about. It is anticipated that through frameworks that aim to link epistemic components, students would have improved understanding of science more broadly. The approaches reported in the paper are about forging connections and consolidating existing understanding. Forging a holistic and interconnected understanding of epistemic aspects of science is likely to promote students' epistemic insight so that they can evaluate, for themselves, what the contributions and limitations of science might be. Future science teacher education will benefit from developing further strategies to support teachers' use of visual representations to express and interrogate epistemic foundations of science.

Acknowledgments The authors wish to acknowledge and thank (a) Selin Akgun and Busra Aksoz for their contributions to the teacher education project, and (b) the pre-service teachers for their participation and for providing data used in the paper.

Funding Information This study receive financial contribution from the Bogazici University Research Fund (Project Number 10621).

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