

Revisiting the Nature of Science in science education: Towards a holistic account of science in science teaching and learning

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Abstract: Nature of Science (NOS) is an area of research in science education that has gained significant attention for several decades. It is a subject that has infiltrated curriculum policy documents, such as the new *Next Generation Science Standards* in the United States, being promoted in teaching and learning of science at the level of the classroom. Yet the precise definition of NOS is a contested territory. For example, the relationship between NOS and scientific inquiry is not agreed upon. In the last few years, the debate around what counts as NOS has been escalating. The presentation will outline some of the recent debates in the science education research community on NOS and argue that the contemporary accounts are limited in their depictions of science. In particular, it will be argued that the so-called consensus NOS accounts tend to be fragmented and not inclusive of science in its broader sense and context. I will illustrate how, for instance, the notion of “scientific practices” can be used to build up a holistic account of science such that students are equipped with a broad range of understandings and skills about NOS. Based on a theoretical interdisciplinary account, we have developed a model that can be applied in teacher education as well as science teaching and learning. The model infuses the relationships between the various epistemic, cognitive and social features of science: (a) epistemic components, such as scientific activities (such classification, experimentation and observation), data, model, explanation, prediction; (b) cognitive components, such as representations, and reasoning; and (c) social components, such as discourse and social certification of scientific claims. An empirical study funded by TUBITAK-Marie Curie Co-Funded Brain Circulation Fellowship will be described to exemplify how a holistic account of scientific practices was promoted in pre-service science teachers’ learning and what the impact was on teachers’ perceptions of NOS. Some recommendations and implications for science education will be discussed particularly in relation to about how science teacher education programmes can infuse more coherent and holistic accounts of NOS.

Introduction

Nature of science (NOS) is a significant area of research in science education and has a history dating back to at least the 1960s (e.g. Abd-El-Khalick, Bell, & Lederman, 1998; Allchin, 2013; McComas, Clough, & Almazroa, 1998; McComas, & Olson, 1998). Chang (2010) traced the literature between 1990 and 2007. The proponents during this period in science education (Abd-El-Khalick, 2012; Lederman et al., 2002; McComas, 1998) have outlined a set of statements that characterize what has been referred to as a “consensus view” of the nature of science. The key aspects of this approach are as follows:

- (1) *Tentativeness of Scientific Knowledge: Scientific knowledge is both tentative and durable;*
- (2) *Observations and Inferences: Science is based on both observations and inferences. Both observations and inferences are guided by scientists’ prior knowledge and perspectives of current science;*
- (3) *Subjectivity and Objectivity in Science: Science aims to be objective and precise, but subjectivity in science is unavoidable;*
- (4) *Creativity and Rationality in Science: Scientific knowledge is created from human imagination and logical reasoning. This creation is based on observations and inferences of the natural world;*
- (5) *Social and Cultural Embeddedness in Science: Science is part of social and cultural traditions. As a human endeavor, science is influenced by the society and culture in which it is practiced;*

- (6) *Scientific Theories and Laws: Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions;*
- (7) *Scientific Methods: There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity.*

The “consensus view” of NOS has led to a major body of empirical studies in science education (Ackerson & Donnelly, 2008; Abd-El-Khalick, & Lederman, 2000). While many science educators agree with the key tenets of this definition of NOS, several points of debate have been prevalent in the community. For example, some authors (e.g. Lederman, 2007) have advised that while NOS and scientific inquiry are related, they should be differentiated. The main premise of this argument is that ‘inquiry’ can be specified as the methods and procedures of science while the NOS concerns more the epistemological features of scientific processes and knowledge. Such distinctions have been criticized by some authors who alternatively argue that NOS cannot be divorced from inquiry, and that the concepts are interrelated (e.g. Allchin, 2011; Duschl & Grandy, 2013).

Inquiry Based Science Teaching (IBST) has centred quite strongly in science education policy and research throughout the world in recent years. For instance, the European Commission’s “Rocard Report” recommends:

“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).

In the context of Turkish science curriculum, for instance, the acquisition of inquiry skills is related broadly to the development of scientific literacy and is promoted explicitly at the primary school level:

“Scientific and technological literacy, broadly defined, is related to individuals’ inquiry, questioning, critical thinking, problem-solving and decision making...” (MEB, 2005, p.5)

The recent educational reform based on recent models necessitates the further articulation of how nature of science and scientific inquiry is to be taught and learned, and further resources and strategies are needed to make the curriculum policy recommendations practical and useful at the level of the classroom. 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. Andreson, 2002; Abd-el-Khalick, Boujaude, Duschl, Lederman, Mamlok-Naaman, Hofstein, Niaz, Treagust & Tuan, 2004). 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 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 the creative exercise of asking questions and being curious about the world around them.

As the development of science speeds up and science becomes increasingly specialized, requiring expert knowledge to be able to make an informed stance, education and dissemination of science meet new challenges. Firstly, there is a need to move from “providing knowledge and ready solutions” towards problem solving and inquiry. That is, a shift from simply conveying the *products* of science towards communicating the *processes* of science. Secondly, science and society are no longer

seen as separate actors where certain institutions have the monopoly on knowledge and other stakeholders (e.g. the public) as receivers of scientific knowledge. On the contrary, bridges with other social actors are being built and the relationship between scientific institutions and other stakeholders is interactive.

A significant shortcoming of the plethora of research studies and policy initiatives on scientific inquiry is the inclusion of an interdisciplinary perspective on science. Despite the rhetoric of “science and society”, contemporary research work on scientific inquiry remains heavily focused on the cognitive, epistemic and social aspects of science without due credit to other aspects of science that hinge upon society and contribute to the definition of scientific inquiry. For instance Erduran & Mugaloglu (2013) argue that the economics aspects of science has not been embraced within the science education community in addressing the nature of science. In a special issue of *Science & Education* focusing on the “Commercialisation and Commodification of Science” they present a theoretical argument for grounding of ‘science’ in science education from an interdisciplinary perspective including economics of science. They illustrate how the commodification and commercialisation of science can be considered in relation to science education in the context of examples such as patents and the metaphors of “market and sub-market” to illustrate the dynamics of knowledge exchange and trade at the level of the classroom between teachers and students, in this case in the treatments of models. They also discuss debates surrounding discoveries and inventions in science in the context of genetically modified organisms. They differentiate their contribution from the conceptually related but historically distinct and different lines of research, namely “Socio-Scientific Issues” (SSI) (e.g. Sadler 2011; Zeidler et al. 2005), “Science-Technology-Society-Environment” (STSE) (e.g. Aikenhead 2003; Gaskell 1982; Yager 1996), “History, Philosophy and Sociology of Science” (HPS) (e.g. Matthews 1994), and “Nature of Science” (NOS) (e.g. Lederman et al. 2002) who have argued for situating science in its historical, socio-political, economic and cultural contexts for educational purposes. However the reference to economics in these research areas has been rather broad with practically no theoretical import from the formal discipline of “economics of science”.

NOS and Scientific Practices

The preceding discussion suggests that NOS cannot simply be seen simplistic and declarative statements about science but rather that it needs to have a coordinated and holistic interpretation to allow for the articulation of the interrelationships between the epistemic, cognitive, social and institutional aspects of science. The more recent concept “scientific practices” begins to address these various aspects of science in a broader sense. The scientific and engineering practices as advocated by the *Framework for K-12 Science Education* contains eight particular practices (NRC, 2012, p. 49):

1. *Asking questions (for science) and defining problems (for engineering)*
2. *Developing and using models*
3. *Planning and carrying out investigations*
4. *Analyzing and interpreting data*
5. *Using mathematics and computational thinking*
6. *Constructing explanations (for science) and designing solutions (for engineering)*
7. *Engaging in argument from evidence*
8. *Obtaining, evaluating, and communicating information*

The *Next Generation Science Standards* (Achieve, Inc., 2013) which followed the NRC recommendations in the USA, have put forward the notion of “scientific practices” as consisting of three spheres of activity: investigating, evaluating and developing explanations and solutions (Figure 1).

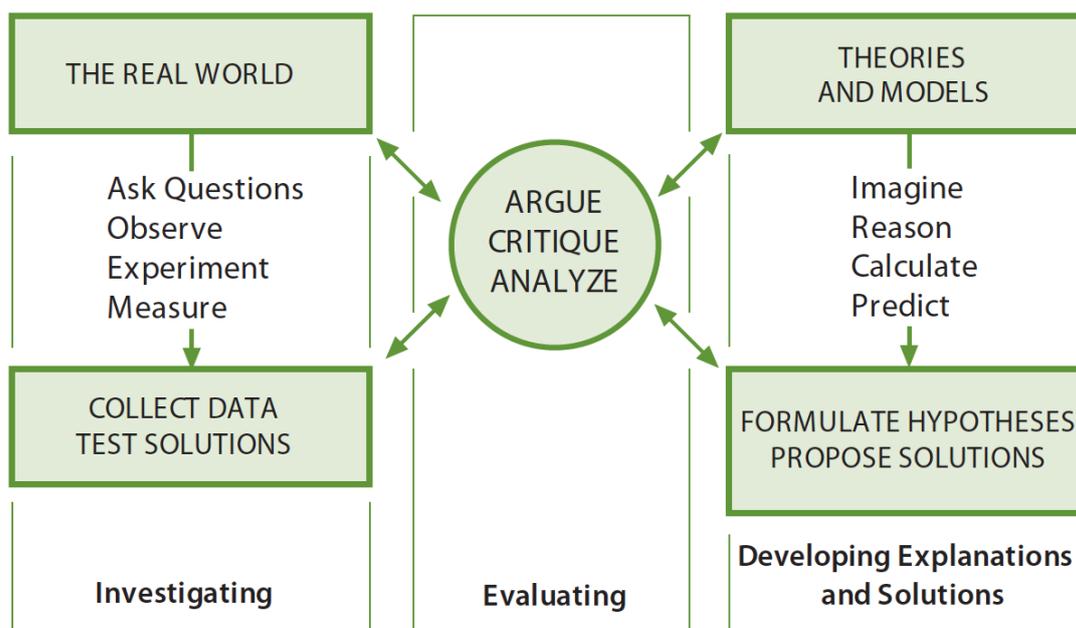


Figure 1. Scientific Practices in the Next Generation Science Standards (Achieve, Inc., 2013)

Scientific practices involve not only the epistemic but also the social-institutional and cultural components that underlie choices made within the enactment of activities. For example, scientists engage in experimentation whereby particular results are derived through controlled trials that are negotiated and discussed within teams of researchers relative to particular evaluative criteria, and reviewed by peers for wider communication (Erduran & Dagher, in press). Scientific practices further include the conceptual and theoretical elements that underlie the choice of tools that are deployed in their constitution. They underscore the discursive relationship between the practices themselves and the individuals and communities by whom they are being practised. Situating activities or processes such as classification and experimentation within the broader practices transforms them from mere activities or processes to grounded practices. The scientific practices involve the collection of data for particular purposes, for instance modeling of phenomena. They involve the coordination of evidence and models through discursive processes such as argumentation. The practices are thus interdependent on one another and service the generation of scientific knowledge. In summary, embeddedness in broader theoretical frameworks and interconnectedness in epistemic, cognitive and social-institutional mechanisms are the defining features of scientific practices.

In our work (Erduran & Dagher, in press), we have generated a model of scientific practices that brings together in a coherent fashion the epistemic, cognitive and social aspects of science. Irzik & Nola (2014) attempted to address the unity of science without sacrificing its diversity by pursuing a Family Resemblance Approach. Basing their notion of family resemblance on Wittgenstein's work, they present their scheme as an alternative to the consensus view, arguing that it is "more comprehensive and systematic" (Irzik & Nola, 2014, p. 1000). The advantage of using the FRA to characterize a scientific field of study is that it allows a set of broad categories to address a diverse set of features that are common to all the sciences and the activities carried out within them. This is particularly useful in science, whereby all subdisciplines share common characteristics but none of these characteristics can define science or demarcate it from other disciplines. For instance, Irzik and Nola present the example of observation (i.e. human or artificial through the use of detecting devices) and argue that even though observing is common to all the sciences, the very act of observing is not exclusive to science and therefore does not necessarily grant family membership. The same applies to other practices such as inferring and data collection, whereby these are shared by the sciences but their use is not necessarily limited to science disciplines.

Figure 2 illustrates the “Benzene Ring” heuristic which serves two primary purposes: (a) it illustrates a holistic approach to representing scientific practices, and (b) it provides a pedagogical tool for communicating about scientific practices. The various epistemic activities of science (e.g. modeling, explaining) are mediated by communication and social certification by peers. Other reasoning and discourse strategies such as argumentation (e.g. Erduran & Jimenez-Aleixandre, 2008) contribute to the formulation, evaluation and revision of claims made about each instance. Science furthermore includes activities such as experimentation, observation and classification which service the generation of data and subsequently models and explanations.

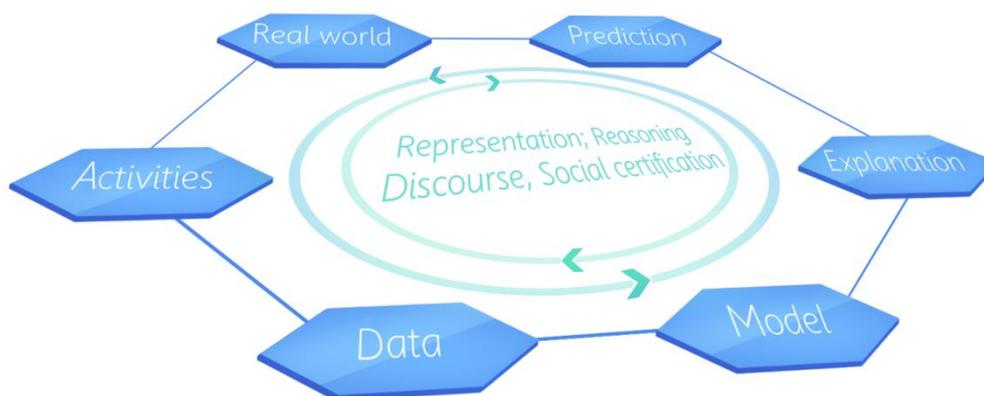


Figure 2. Benzene Ring Heuristic of scientific practices

The empirical part of our work, funded by TUBITAK-EU Marie Curie Brain Circulation Scheme Fellowship aimed to investigate how preservice science teachers perceived scientific practices.

Methodology

The overall aim of the project is to investigate how scientific practices can be defined from an interdisciplinary perspective and subsequently integrated, implemented and learned in the context of pre-service science teaching. Three workshops were held each emphasising a particular aspect of scientific practices, and there will be an agenda to build on the participants' understanding and skills through peer discussions, collaborative investigations and reflection, strategies suggested by teacher education literature to be effective in promoting teachers' learning (e.g. Darling-Hammond, 2006). The three workshops focussed on particular features of scientific practices. The first workshop was included open ended investigations to build up some of the features of scientific practices. For example, there were tests with acids and bases where students were asked to build models and explain characteristics of acids and bases. The activities of observation and modeling were thus introduced. The second workshop introduced the Benzene Ring heuristic which was used in relation to some lesson materials. Preservice science teachers were asked to investigate the lesson plans to determine which aspects of scientific practices were included in them. The third workshop gave the students a chance to begin lesson planning of their own to integrate scientific practices into teaching and learning. The workshop materials have been collated and turned into professional development resources, and will be disseminated as part of the project outputs.

The overall TUBITAK-Marie Curie Project consists of several interrelated studies that address the broader goals of integrating the teaching and learning of scientific practices. Here two of these studies will be illustrated.

Study 1: Student teachers' perceptions of scientific practices

The study focused on preservice science teachers' perception of scientific practices, including its features, the relationships between the features and the holistic understanding of scientific practices. Moreover, the study investigated the influence of an intervention on preservice science teachers' understanding of scientific practices. The intervention was specifically designed to develop preservice science teachers' understanding of scientific practices based on Benzene Ring heuristic.

This study was guided by the following questions: (a) What are the preservice science teachers' perceptions of scientific practices before and after the intervention? (b) Are there any significant differences between preservice science teachers' pre and post perceptions of scientific practices? 21 (18 female, 3 male) preservice science teachers, third year students in a science teacher training program in Turkey participated in the study. The perception of scientific practices (PSP) questionnaire is used to assess preservice science teachers' perception of scientific practices. The test is comprised of two parts. The first part includes 36 items. Each response is scored on a five-point Likert scale with response options ranging from 1-"strongly disagree" to 5-"strongly agree". The test has three dimensions, which are features of SP (6 items), relationship between the features of SP (14 items) and holistic understanding of SP (16 items). The second part consists of 4 questions. In the first question, preservice teachers are asked to draw a concept map with the given features of scientific practices. The rest of the questions are open-ended.

Analysis of the first part of the test included descriptive statistics illustrating the mean, minimum, maximum and standard deviation (Table 1). Wilcoxon test was used to investigate the difference between the pre and post scores.

Table 1. Results from Perceptions of Scientific Practices Questionnaire

	N	Min 6/14/16	Max 30/70/80	Mean	Std. dev.
Pre_dim1	21	21.00	27.00	24.57	1.72
Post dim 1	21	22.00	29.00	25.57	2.06
Pre_dim2	21	48.00	57.00	51.33	2.46
Post-dim2	21	47.00	63.00	52.81	3.83
Pre_dim3	21	47.00	60.00	53.52	3.30
Post-dim3	21	51.00	67.00	57.24	4.52
Pre_total	21	119.00	144.00	133.05	5.45
Post total	21	123.00	147.00	135.62	6.60

The results illustrate a significant difference in dimension 2 which concerns the holistic understanding of scientific practices. There were no significant differences in the other dimensions.

Study 2: Student teachers' representations of scientific practices

The primary purpose of this study was to investigate pre-service science teachers' representations of scientific practices. The participants were tasked with the drawing of a poster of scientific practices before and after the implementation of a series of workshops that aimed to instill in pre-service teachers a particular model of scientific practices based on a heuristic developed by Erduran &

Dagher (2014). The heuristic relies on the incorporation of the epistemic, cognitive and social-institutional aspects of scientific practices in a holistic and visual representation.

The following research questions guided the study: (a) What are pre-service science teachers' representations of scientific practices? (b) How does an intervention on scientific practices influence pre-service science teachers' representations of scientific practices? The data sources are (a) drawings of scientific practices by groups of pre-service teachers before and after the implementation of the intervention, (b) group verbal discussions captured on audio-recordings, and (c) individual interviews with participants in group discussions. Qualitative research methods are used, generating codes through iterations of observations of posters and verbal data from individual interviews and group discussions. Qualitative data are investigated through a grounded approach, generating and categorising data. Inter-rater reliability of the codes will be established through discussions and resolved if there are any disagreements in the way that the representations are being conceptualised.

Representations of groups of pre-service teachers were identified on the basis of an analysis of their drawings. Investigation of the drawings suggested 5 key categories which showed qualitative differences between the posters drawn pre- and post- intervention. The terms used to construct the drawings could be placed in various combinations to each other. Some students chose to link these terms in a linear fashion, while others had more cyclic representations. In some instances hierarchies were used in combination with either linear or cyclic representations.

In the following paragraphs, each poster type will be described and illustrated with photographs of the posters before and after the intervention workshops.

Case 1: Linear to circular

In the pre-poster of case 1 (Figure 3) there is a linear representation of scientific practices. The group classified scientific practices as "asking question, determining the problem, collecting data, constructing a hypothesis, testing hypothesis, analyzing the data, and communicating results" in a linear order. They determined "asking question" as the first step in a scientific procedure. The other practices follow each other in an ordered way. However, in the post-poster of case 1, the group determined scientific practices different than the pre-poster and presented these scientific practices as circular. They also classified scientific practices as "real world, prediction, model, activity, data, and explanation". In this circular representation of scientific practices, they used a chemistry context, specifically acids and bases. For example, they drew some objects such as salt, soap, lemon, and orange as examples of real world.



Figure 3. Pre- and post-intervention posters indicating linear and circular representations of scientific practices

Case 2: Part linear-part circular to circular

The pre-poster of case 2 (Figure 4) shows part linear-part circular representation of scientific practices. The group starts with "Question" as a scientific practice at the top of the representation. Then they classified "Question" as "Scientific Activities" and "Observation" and also specified question requires scientific activities and/or observation. They combined scientific activities and observation as "Data" and stated "enable us to construct" on the arrows. Therefore, the group presented a circular representation of scientific practices at the top of their poster. The other part of the poster shows a linear representation of some scientific practices which are "Data", "Prediction", and "Model". The group connected "Data" to "Prediction" with the statement of "give an opportunity to make" and connected "Prediction" to "Model" with the statement of "provides us to construct a". However, in the post-poster of case 2, the group classified scientific practices as "Reality", "Model", "Argumentation", "Explanation", "Discussion", "Scientific Activities", "Data", and "Prediction" in a circular system. They did not use any arrow with a specific way between these scientific practices; they just used lines between them.



Figure 4. Pre- and post-intervention posters indicating part linear and part circular representations of scientific practices

Case 3: Linear and hierarchical with new connections

The pre-poster of case 3 (Figure 5) starts with "Discussion", "Prediction", and "Data" with a linear order. The group wrote "A problem or argument is determined" in the discussion part and they also put some question marks here to show the problem situation. After discussion, prediction is made. And then data is generated. Data goes to "Scientific Practices". At this point, they classified scientific practices as "Modeling" and "Experimenting". In "Modeling", "Observation" is made and in "Experimenting", "Explanation" is made. Then, the group finished put "Review of other scientists" at the bottom of the poster by combining observation and explanation. They did not use any arrow between the concepts in the poster, just used lines between them. In the post-poster, the group starts with "Real world events", "Problem", and "Data". They connected real world events and problem with the sentence of "by looking the nature, we can observe some changes and we would like to understand how it happens. It gives us a problem". They classified data as "Model" and "Prediction". They also put "Argumentation" as another connection in the poster and stated that argumentation may occur for all steps.

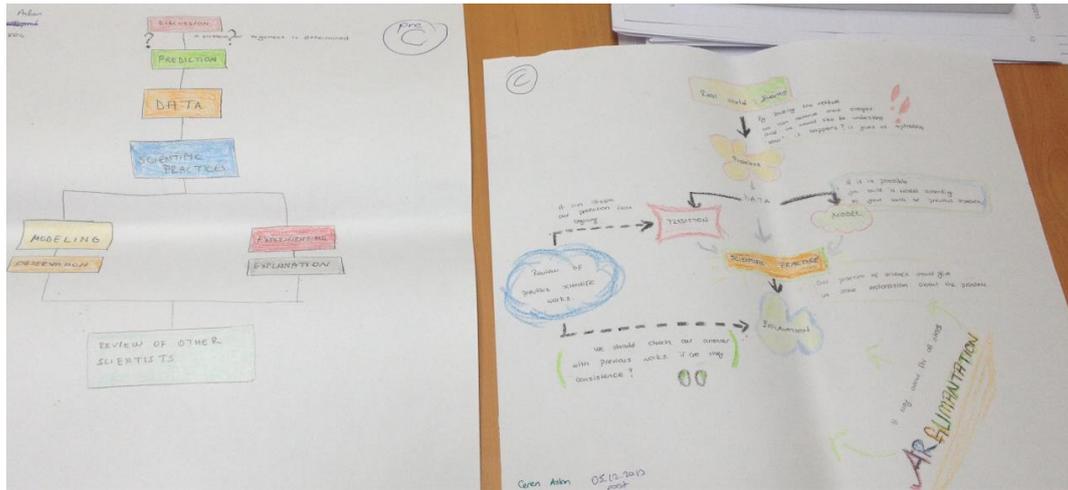


Figure 5. Pre- and post-intervention posters indicating linear and hierarchical representations of scientific practices

Case 4: Conceptual (not epistemic) characterisation both pre and post intervention

In the both pre- and post-poster of case 4, there is a conceptual not epistemic representation of scientific practices. In the pre-poster, the group presented the concepts of ecosystem such as photosynthesis, vaporization, decomposers, glucose, CO₂, O₂, N₂. For photosynthesis, they drew a sun, a tree with some arrows from sun to tree, from tree to gases like CO₂ and O₂. They also showed the cycle of N₂, considering decomposition of N₂ in air by plants in earth. They drew a rabbit as a consumer of O₂ and releaser of CO₂. In the post-poster, the group added new concepts such as data, inferring, real world, model, argumentation, and analyzing data. They considered all these concepts in terms of pedagogical context. They stated the drawing of ecosystem cycle as “Model”. In this cycle of ecosystem, there were sun, tree, rabbit, and decomposers. They modeled this from “Real World”. They wrote “Data” after “Real World”. Under data, they put photosynthesis, respiration, nitrification, and vaporization as examples. They also explained that all these components (photosynthesis, respiration, nitrification, and vaporization) are related to each other. And they stated that “teacher expect students to make connection among them” and named this as “Inferring” in the poster. Finally they connected inferring to “Argumentation” by the sentence of “Students may make predictions about the ecosystem. For example, they estimate that consumers such as animals take oxygen and glucose (to make respiration) from photosynthetic living creatures (like from tree), which produce oxygen and glucose”. They also explained argumentation as “Children discuss the topic known as ecosystem after all these concepts. Because of this, they vary their opinions by affecting each other”.



Figure 6. Pre- and post-intervention posters indicating concepts without epistemic characterisation of scientific practices

Case 5: Linear to Linear

The pre-poster of case 5 shows a linear representation of scientific practices. The group classified scientific practices as six steps following each other. For the first step, they wrote “scientific practices begin with a question or curiosity” and put a big question mark here. The second step is making an educated prediction about a specific topic. The third step is creating a model or experiment mechanism to make an observation. The following step is making an observation recording whatever we see. The next is making logical explanation to support the prediction that we created at the beginning of the process. The last step is evaluating the result and discussing what we did, and thinking about the reliability of our scientific activity. In the post-poster of case 5, the group shows again a linear representation of scientific practices but with a four steps classification and in a chemistry context which is different than the pre-poster. They formed their poster based on the topic of atom. As the first step of scientific practices, they wrote “Our scientific activity begins with a question that is what is the smallest structure of that forms matters in real world?”. Here, they considered both real world and asking questions from real world. As the second step, they wrote “Students make predictions. Then we offer materials to model the structure of the matter. Here, they considered both prediction and modeling. They also used models to explain this step. They drew pictures indicating atom, element, compound, and molecules. For example, for the atom model, they drew circles to represent atoms with same colors. For the element model, they drew two elements. One of these elements is composed of four atoms with red color; the other is composed of two atoms with blue color. And for the compound model, they drew two compounds. They used atoms with different colors to show the compound.

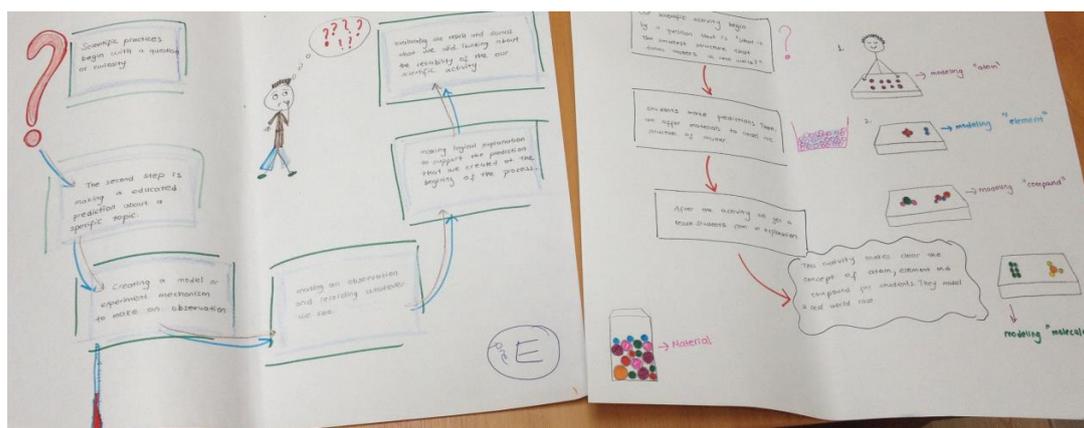


Figure 7. Pre- and post-intervention posters indicating linear characterisation of scientific practices

Conclusions and Implications

The sample studies presented in this paper illustrate that even in a short span of an intervention, preservice science teachers were able to integrate aspects of scientific practices into their thinking. There was a particular difference in their thinking about scientific practices in a holistic sense. The group work on representations of scientific practices illustrated a range of depictions, some of which indicated that there was uptake and influence of the Benzene Ring heuristic (for example, Figure 3).

The intervention described in the paper introduces a new way of thinking about NOS in science teaching and learning. Rather than a set of declarative statements about science, the Benzene Ring heuristic incorporates the epistemic (e.g. modeling), cognitive (e.g. reasoning) and social (e.g. discourse) aspects of science into a holistic representation thus communicating a broader notion of science in science education. The heuristic also provides links to the notion of “scientific inquiry” through the various activities that can be conducted in order to generate the data that in turn form the basis of modeling and explaining.

Effective professional development in science education requires sustained and long-term investment in teachers' learning (e.g. Erduran, Yan & Park, 2011; Erduran, Yee & Ingram, 2011; Erduran & Yan, 2009; Erduran, Ardac & Yakmaci-Guzel, 2006). The project described here can be considered a pilot for longer term and elaborate set of interventions that can communicate the theoretical reconceptualisations of NOS. The results of the study, however, are encouraging in that preservice science teachers were in some instances at least were able to make more connections between the different aspects of scientific practices following a sequence of workshops. development. Overall the ideas reported in the paper contribute to the recent debates on characterising the NOS and extends definitions of NOS to be more holistic, coordinated and visual.

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