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Learning to teach scientific practices: pedagogical decisions and reflections during a course for pre-service science teachers

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Abstract

Background: This auto-ethnographic study describes research conducted in a science teacher education program at a state university in Turkey, where I had taught the 'laboratory applications' course for the four previous years. While the students learned the basic skills needed to implement a laboratory course, I detected some deficiencies in their understanding of scientific practices. Consequently, I decided to adopt a different approach. In the fall of 2013 to 2014, I participated in a project aimed at improving pre-service science teachers' understanding of scientific practices (SPs) using a model known as the Benzene Ring Heuristic (Erduran and Dagher 2014).

Results: This project helped me to re-design my course, emphasizing the integration of SPs into lesson planning and teaching. As I taught the re-designed course, I gathered data from various sources, including pre- and post-interviews, audiotape recordings of lessons, students' lesson plans and reflections, and my own and my colleague's reflections after teaching.

Conclusions: The data suggest that my students' understanding of SPs improved, but I was still not satisfied with their understanding of domain specificity, ethics, and utility in science, or with their beliefs about the roles and responsibilities of students during science lessons. These are issues to be dealt with as I continue to try to improve the course.

Keywords: Auto-ethnography; Scientific practices; Professional development; Pre-service teacher education

Background

I completed my PhD in the spring of 2008, and since the fall of 2009, I have been working as an instructor at a state university in Turkey, teaching pre-service science teachers the methodology of science teaching. The purpose of my courses has been to further their understanding of science and the scientific method and to enable them to design and implement science lessons. Currently, the goal of my 'laboratory applications' course is to provide pre-service science teachers with the analytical and communicative skills needed to design and implement laboratory instruction. In the content of this course, I introduce science process skills and inquiry-based instruction. Furthermore, I present various pedagogical approaches, from a verification approach to an open-inquiry lab, while asking questions and offering opportunities for cooperative and collaborative learning.

From my teaching experience, I inferred that although my students were able to design and implement an inquiry-based science lesson, I did not succeed in making them understand the underlying science. Most of the pre-service teachers finished the course with a limited understanding of science. The following list summarizes the problems I found in their reasoning about science and the scientific process:

- They regarded the scientific method as a step-by-step procedure beginning with a question and ending with results, despite my emphasis on the iterative nature of science as opposed to a recipe-like procedure.
- All my students included communication skills in their lesson plans (LPs) and discussed them in their reflections. However, the discussion part of their reports contained very limited information about discourse or discussion in teaching. They noted only that the students discussed their views during classroom activities. Moreover, they showed little or

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no understanding of the role of discourse and social certification in the scientific process.

- Most of the pre-service teachers regarded science as including mainly observation and/or experimentation, and they underestimated the significance of modeling in scientific work even though I had discussed modeling during the lessons. Only one group out of ten used modeling in their first LP.
- My students exhibited the misconception that scientific activities aim to verify facts, concepts, and hypotheses. Even after I had introduced different pedagogical approaches, science process skills, and inquiry, and after their implementations of LPs, one of my students declared that experiments and models are made to verify information. This misconception may have arisen from the traditional science courses that she had taken. It is evident that the different pedagogical approaches presented in the course had not removed this misconception.

Such problems led me to conclude that I needed a new approach in my teaching. I also thought that I might find other misconceptions about the nature of science if I probed my students' thinking.

Scientific practices

In recent years, examination of the nature of science (NOS) has led both educators and researchers to discuss 'the scientific worldview', 'science as a way of knowing', and 'scientific practices' (American Association for the Advancement of Science 2009; Duschl and Gitomer, 1991; Lederman 1999; McNeill 1998) and to disseminate the 'notion of whole science' (Allchin 2011), which emphasizes the multiple dimensions of science. According to Allchin (2011), the 'Whole Science approach underscores the role of rendering the integrity of scientific practice' (p. 526). So what are these scientific practices (SPs)?

The *K-12 Science Education Framework* of the National Research Council (NRC) proposes eight practices reflecting the eight essential elements of the K-12 science and engineering curriculum:

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 (2012, p. 49)

Research concerning SPs in 'Taking Science to Schools' (TSTS) (National Research Council 2012) showed that children increase their capacity for complex reasoning and develop their cognitive ability when they are engaged in SPs such as predicting, observing, testing, measuring, counting, recording, collaborating, and communicating. TSTS (National Research Council 2012) also concluded that SPs widen students' knowledge and understanding of scientific concepts and principles (cited in Duschl and Grandy 2013).

Although the essential components of SPs are well known and thoroughly discussed in the literature, there may be different ways to indicate the relationships between these components, one of which is represented in the Benzene Ring Heuristic (BRH) designed by Erduran and Dagher (2014).

Benzene Ring Heuristic

SPs have epistemic, cognitive, and social-institutional components that scientists use and science learners can learn to use (Duschl and Grandy 2013). Considering this point of view, Erduran and Dagher (2014) proposed a heuristic bringing these aspects of science together. Their initial heuristic is illustrated by an analogy to the benzene ring and the relationship between its components (Figure 1).

The benzene ring is an organic compound that consists of six carbon atoms and six hydrogen atoms joined together in a ring with single and double bonds. The heuristic shows epistemic and cognitive aspects of science that are interrelated and influenced by social dimensions in a holistic illustration. The epistemic components are linked to one another by dynamic socio-cognitive processes represented by the electron cloud, indicating representation, reasoning, discourse, and social certification (Erduran and Dagher 2014).

A significant contribution of this heuristic is that science process skills that are fundamentally different aspects of science are no longer isolated but included in the same illustration by showing their interactions within other SPs (Erduran and Dagher 2014). I was impressed by this heuristic in my search for a way to develop pre-service teachers' thinking about science, and I decided to introduce BRH to the students in my course.

My aim here is to present my interpretations of teaching a holistic approach to science using BRH and to bring my perspective of teaching and learning science into the realm of educational research. More specifically, the problems I found in my students' reasoning about science and the scientific process led me to conclude that I should implement a new approach to answer the following question: how can I improve my teaching in order to develop pre-service science teachers' ways of thinking about science by integrating SPs into my

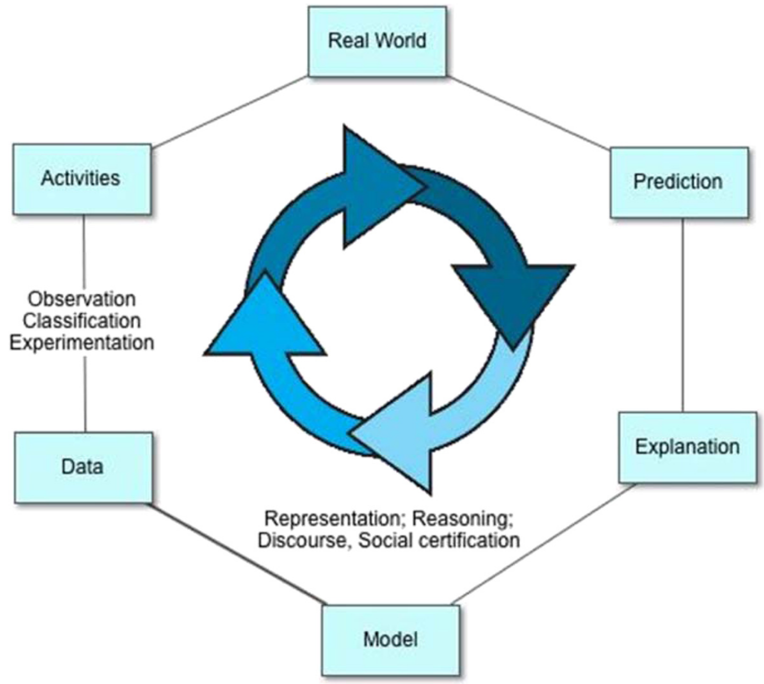

Figure 1 Benzene Ring Heuristic (BRH).

teaching? Auto-ethnography, which comprises 'highly personalized accounts that draw upon the experience of the author/researcher for the purposes of extending sociological understanding' (Sparkes 2000, p. 21), is an appropriate method for this task.

Auto-ethnography

With the advent of post-modern research, ethnographic and auto-ethnographic writing practices have gained in favor (Holt 2003; Reed-Danahay 1997). Although there are various definitions of ethnography, ethnography in education specifically is defined as 'research on and in educational institutions based on participant observation and/or permanent recordings of everyday life in naturally occurring settings' (Delamont and Atkinson 1980, p. 139). On the other hand, auto-ethnography in education is taken to be a form of self-reflection that aims at presenting a teacher-educator's subjective experience as a researcher, combining this narrative with theoretical frameworks of wider phenomena (Hamilton et al. 2008). According to Ellis and Bochner (2000), auto-ethnographic studies differ in the sense that they emphasize the 'auto' (the self), 'ethno' (cultural elements), and 'graphy' (the research process) (as cited in Reed-Danahay 1997). From this perspective, Ellis and Bochner (2000) considered auto-ethnography as 'exposing a vulnerable self that is moved by and may move through, refract and resist cultural interpretations' (p. 739). From Ellis's perspective (2004), the cultural component is crucial in auto-ethnographic research and 'in an educational context, culture could be addressed as language, action, and/or interaction' (Hamilton et al. 2008, p. 23).

There are two types of auto-ethnography, each with a different purpose. According to Ellis and Bochner (2000), the mode of storytelling in *evocative auto-ethnography* 'is akin to the novel or biography and thus fractures the boundaries that normally separate social science from literature' (p. 744). According to Anderson (2006), *analytic auto-ethnography* is characterized by '(1) Complete member researcher, (2) Analytic reflexivity, (3) Narrative visibility of the researcher's self, (4) Dialogue with informants beyond the self, (5) Commitment to theoretical analysis' (p. 378).

This paper takes the form of analytic auto-ethnography. I will describe the method of the study, how I decided to improve my teaching, how I implemented the heuristic of SPs into my teaching, and what happened during the lessons.

Methods

With the aim of implementing a new approach to my teaching, I participated in a project entitled 'Revisiting Scientific Inquiry in the Classroom: Towards an Interdisciplinary Framework for Science Teaching and Learning'. It was supported by TUBITAK and the European Union Marie Curie Co-Funded Brain Circulation Scheme Fellowship (291762/2236) and was offered at a state university in Turkey. The aim of this project was to investigate the impact of an intervention based on a heuristic of scientific processes on pre-service teachers' perceptions and reasoning. The heuristic is based on an interdisciplinary account of SPs and draws on the relationships between the various epistemic, cognitive, and social features of SPs. Components of the heuristic include (a) epistemic components such as scientific activities (classification, experimentation, and observation), data, model, explanation, and prediction; (b) cognitive components such as representations and reasoning; and (c) social components such as discourse and social certification of scientific claims.

With the help of this project I undertook the procedure of implementing SPs on BRH to improve my teaching for developing my students' understanding science. The project recommended the inclusion of three workshop sessions in a course, each of which would last for approximately three hours. The course normally had three lecture hours and two lab hours per week. I conducted the lecture sessions, and the second author, the course assistant, conducted the lab sessions. Previously, the second author had worked as a middle school science teacher for eight years. In our lab sessions, she helped the pre-service teachers to search the web for sample LPs, and when they were about to teach, she helped them to prepare their lessons.

Thirty-six pre-service teachers participated. They were divided randomly into two sections, one in the morning ($n = 23$), the other in the afternoon ($n = 12$). The second author attended the morning sessions, and the coordinator of our project attended most of the sessions as an observer. The course was taught in English, which for the students is a second language.

This course was designed in two phases, the first of which includes introducing and discussing science process skills and inquiry, and the second phase of which consists of asking questions during instruction and cooperative and collaborative learning. Both phases ended up with pre-service science teachers' implementation of their LPs that they designed with their teammates in microteaching hours. After their microteaching experiences, they submitted their reports of LPs including their individual reflections.

At the beginning of the course, pre-service teachers were asked to form groups of three or four pre-service teachers to design and implement a lab lesson on a science topic. In the first phase of the course, safety, science process skills, inquiry, and different pedagogical approaches, ranging from a traditional teaching approach to the open-inquiry type of instruction in science teaching, were introduced throughout three weeks, and in the following three weeks, pre-service teachers presented their LPs in groups in microteaching hours. Then they submitted their group reports of these LPs including an individual discussion part in which they reflected the theoretical information they integrated into their plans as well as their experiences during microteaching hours.

In the second phase of the course, asking investigable questions during instruction was introduced to pre-service teachers and increasing the inquiry level of the instruction was discussed by using these questions in previous years. In the following week, the importance of collaboration and cooperation in science and science education was discussed. In this phase, pre-service teachers were responsible to choose a science topic other than their first LPs and again design and implement a lab lesson. Then they submitted the group reports of their LPs in groups again including an individual discussion part.

I gathered data from various sources, including pre- and post-interviews, audiotape recordings of lessons, students' LPs and reflections, and my own and my colleague's reflections after teaching.

Results and discussion

In this section, I will analyze the problems that I observed before the intervention, the use of BRH to solve the problems, and the change in the understanding of students upon implementation of the BRH in workshop sessions.

How I decided to improve my teaching

In my four years of teaching, my courses adequately enabled pre-service teachers to acquire the skills needed to design and implement inquiry-based lab lessons that served to improve students' inquiry and science process skills. I assumed that my students could identify and explain the process skills they used in their LPs. For example, when reflecting about the course, one of my students wrote:

> *In this course, I learned how a laboratory lesson plan is prepared well and its specific characteristics. Laboratory work can be different kinds of inquiry levels based on students' cognitive and developmental skills. If we increase the inquiry level of lesson, we should provide more usage of students' basic and integrated process skills. However I learned laboratory work should be related with the class work and emphasized hypothesis, predicting, developing concepts, model building and developing positive attitudes toward science. If our lesson style allows students to make their experiment by observing, inferring, measuring, classifying, predicting and communication, their science skills will be developed. That means students' practical, inquiry and teamwork skills should be developed.*

Another student described the science process skills in LPs as follows:

> *Students measured the time by adding yeast solution to the tubes (measuring) and after waiting for a while they observed the color change in the tubes (observing)… students thought about the reason of the color change in the tubes (predicting) and also at the end, they found the reason why these materials used in the experiment (inferring). In the discussion part of the experiment, they shared their ideas with each other… (communicating). Besides the basic science process skills we also used some integrated science process skills in our lesson such as experimenting and fair testing and control of variables. We did experimenting because in experimenting, there is an investigation by trial and error. In our lesson, students made some investigations by adding some materials to the tubes. In addition, we used fair testing and control of variables. That is, we had dependent, independent and control variables in our experiment.*

I inferred from their reflections that they could list and discuss the basic skills of observing, measuring, predicting, inferring, classifying, and communicating, and the integrated skills of hypothesizing, identifying and controlling variables, defining operationally, designing experiments, analyzing data, and interpreting results. However, understanding science is not only a matter of identifying and explaining the components of scientific processes. It also includes a holistic understanding of domain specificity in science, the role of social discourse and social certification in a scientific process, and ethics in science.

Before the intervention, when asked to represent their understanding of SPs, four out of nine groups drew a linear sequence in the following order: ask a question, determine the problem, collect data, construct a hypothesis, test the hypothesis, analyze the data, and communicate the results. Their drawings revealed their lack of a holistic understanding of science. Also, only one student in all the pre-course interviews had mentioned discourse or social interaction when asked to list the components of SPs.

Before beginning this study, I had never thought about probing my students' views about ethics and utility in science. After my students brought up ethical issues during their interviews, I thought that I should also consider ethics when re-designing the course. An interviewee in her pre-interview said that one feature of SP is to follow the proper ethical rules. I thought that she was right and that I ought to discuss this issue during my teaching.

Realizing that my students lacked a holistic understanding of SP, I decided in the fall semester of 2013 to 2014 to participate in the above-mentioned project. The heuristic that was used in this project aroused my interest because science literature has long emphasized the generalizations of scientific method and claimed that there is no one way for doing science, no universal step-by-step recipe-like procedure (Abd-El-Khalick 2012; Duschl and Grandy 2013; Lederman and Adb-El-Khalick 1998). For this reason, science education must be grounded in a holistic approach in which students recognize that scientific methods are diverse and that the essence of science is the accumulation of evidence in support of claims.

There has been a debate about the characterization and teaching of science over the last decade. Two different positions have emerged in this debate: Version 1 advocates that science should be taught using domain-general and consensus-based aspects of the NOS; version 2 says that science is characterized by cognitive, epistemic, and social practices, and that science should be taught by engaging students in domain-specific practices. According to version 2, students learn to use these practices when developing evidence-based explanations and when communicating ideas (Duschl and Grandy 2013).

Discourse practices of science, such as argumentation, modeling, and critiquing, are central in version 2, while these practices are missing in version 1 (Duschl and Grandy 2013). This is why I favored the position of version 2 and decided to incorporate it into my teaching. Furthermore, included in the dimension of reliability in SP are ethical considerations (Allchin 2011). I wanted my students to consider and appreciate ethics in science.

How I implemented the heuristic of SPs into my teaching

At the beginning of the fall semester of 2013 to 2014, the students were asked to form groups of three or four, and each group was given the assignment of planning and implementing two microteaching lessons. After introducing the theoretical background to a selection of pedagogical approaches, science process skills, and inquiry, the second author and I gave each group a topic for the first LP, recognizing that this would be the students' first microteaching experience in a teacher education program. After the groups had designed and implemented their LPs, their classmates and I gave them feedback in terms of science process skills and inquiry levels, and then they wrote their own reflections about what they had done. During this time, we conducted pre-interviews with ten of the pre-service teachers for the purpose of recording their perceptions and ideas about SPs. I will provide sample statements from those interviews in the next section of this paper.

After the first microteaching presentations, we implemented the workshops, and following these workshop sessions, my students presented the second of their LPs, this one on a topic their group had chosen (Additional file 1: Appendix 1).

What happened during the sessions?

Before introducing SPs, but after teaching the topics of science process skills - inquiry, instructional types, and pedagogical approaches - I asked the pre-service science teachers in their groups to construct a concept map to show their understanding of SPs. After the intervention, they constructed a second map to record a change in their understanding, both of SPs and the BRH.

The aim of the first session was to make the pre-service science teachers engage in a discussion around the notion of SPs in order to elicit their initial understanding. For this purpose, I introduced the BRH developed by Erduran and Dagher (2014). Throughout this session, I described specific SPs and how they can be applied in a science lesson by conducting a sample activity on the subject of acids and bases. I wanted the students to see the relationship between these SPs in the context of a lesson. One of the students later reflected 'They help to teach a subject to students in a more effective way'. Another student wrote:

> *I learned what scientific practices are and how we can apply them in our lessons. That is, there are various scientific practices and each of them can be a part of our lesson. There are also some relationships between these scientific practices and they form content of the lesson. Therefore, when I create a lesson plan, I can teach a subject to students in a more effective way by using them.*

The students had various responses to the relationship of scientific concepts as exemplified by the BRH.

- One of the students defined the heuristic as *'having a continuous relation and this relationship specifies the format of instruction'. However, some could not comprehend the continuity of the heuristic and asserted that the 'benzene shape provides the basic titles; however the path teacher may follow should not be restricted. Teacher and candidates should change the order and jump to one scientific practice to another. Benzene shape should include flexibility'.*
- Some were confused about the components of the heuristic and had difficulty in applying it to the activity. For instance, one student stated *'At first glance, I couldn't understand the concept of modeling and data. Therefore, I said that modeling is not necessary and we can remove it from our microteaching'.*

Although the heuristic caused some confusion, opinions were clearer at the end of this session when the students realized that they can create different LPs about a given subject by using SPs in different ways and in sequences different from the BRH. They made such statements as:

> *I realized that it is important to make lesson plans including appropriate scientific practices so that it can facilitate learning for students.*

> *The entire lecture showed me using scientific practices was useful for students to capture their perceptions toward topic.*

I found these reflections encouraging. The session ended with reinforcement of the interconnection between the components of SPs.

The purposes of the second session were first to strengthen the students' understanding of the heuristic by applying it to particular science examples and then to initiate the design of LPs. The students started the session by reviewing and discussing the examples that they worked on in the previous session. Then they discussed the connections between the different examples and the different components of SPs. They were able to determine the SPs used in the samples by pointing out components of the BRH. Then I asked them to outline a LP on a topic of their choice and to discuss the SPs that might be used in the lesson. Following this activity and discussion, they reflected on what they had learned about lesson planning and the impact of the group work on their understanding of lesson planning. The following quotation is from a group reflection on the role of SPs in a LP:

> *Lesson planning should be very structured and every step has the aim. Introduction, activity and conclusion play a vital role in lesson planning. In group work, modelling part become more comprehensible. Prediction may appear in every part of the activity. Experiences, real world and lesson is effective for students and also science education. Predictions shape the understanding of real world and real world shapes predictions. Whether the conclusion is right or not, it is more important to comment conclusion and to discussion in a right way.*

The aim of the third session was to engage the pre-service science teachers in evaluation and revision of earlier models, using three examples based on different pedagogical approaches, ranging from a verification approach to an open-inquiry approach. Each example addressed a different topic. The first example was about phases of water, the second about an aquatic ecosystem in a bottle, and the third about modeling the Earth's crust. After the students had determined the SPs used in these sample LPs, they created a second concept map. Figure 2 gives an example of concept maps before and after the intervention of the workshops.

The sample pre-intervention concept map shows that these pre-service teachers were able to indicate the relationships between the components of SPs in a part linear, part circular representation. This representation shows a circular relationship between the scientific activities of observing, data gathering, and questioning, but a linear relationship between those of data gathering, predicting, and modeling. However, the post-intervention concept map shows that after the intervention, they were able to demonstrate the holistic approach in a circular representation associating the cognitive (explanation), epistemic (model making), and social (argumentation) aspects of science (Erduran and Dagher 2014) in a circular manner.

When the second author and I were explaining and comparing my students' concept maps in class, they emphasized the change in understanding of the sequence of SPs in the BRH. After participating in the acid-base activity and the classroom discussion about different pedagogical examples, my students were more aware of the divergent use of SPs. One of the pre-service science teachers claimed *'BRH helps the teacher to prepare a better and organized lesson plan'.*

In the second microteaching performance, which took place after the workshop sessions, the pre-service teachers were required to use the components of the BRH. Most of the groups used modeling, since it was new for them, a departure from their earlier idea that experiment is the only kind of scientific activity. Comparison of the two microteaching performances made it evident that the BRH had helped them be more organized in the second performance, and the difference was noted in their written reflections. Furthermore, the opportunity to apply the BRH in microteaching broadened their understanding of SPs and the incorporation of SPs into lessons, because they had become aware that each LP employed a different type of application.

Holistic understanding of SPs

The students who had drawn a linear sequence of the scientific method in their first concept maps - ask a question, determine the problem, collect data, construct a hypothesis, test the hypothesis, analyze the data, and communicate the results - represented SPs as a circle in their second concept maps, specifically about acids and bases. They identified real-world phenomena (referring to commonplace objects such as salt, soap, lemon, and orange), predictions, models, activities (observation and experiment), data (gathered from the experiments by using litmus paper), explanation (numerical values of acids and bases), and social certification (represented by a smiling sun) as SPs.

The following quotation from the second author's reflection captures some of the benefits of this workshop:

> *One of the students explained her opinion about the scientific practices as they help to teach a subject to students in a more effective way. In addition, they learned the Benzene Ring Heuristic showing the relationship among scientific concepts. …*
>
> *In the second session, the instructor introduced different lesson plans that are based on different pedagogical strategies and wanted them to differentiate the scientific practices that are used. The students were able to determine the scientific practices used in the samples and had a better understanding about the use of BRH. They were also asked to think of different ways to plan these lessons by using different scientific practices or in different order. This session helped students to make it clear for the application of BRH in*

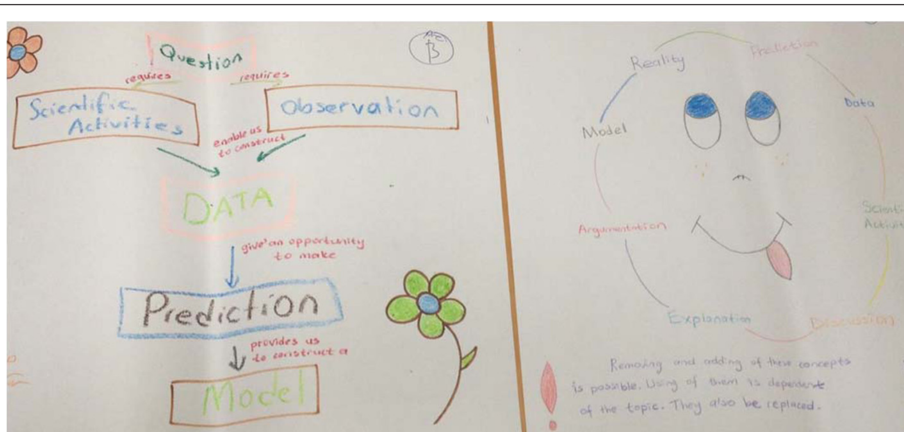

Figure 2 Pre- and post-intervention concept maps.

different subjects and for the correction of confusions of the students about the order of the scientific practices.

In the last session, students created the second concept map in order to observe the change in the understanding of the scientific practices and BRH. When they were explaining their concept map and the comparison with the first one, they mostly put emphasis on the change in the understanding about the sequence of the scientific practices in the benzene ring model. After the application of the acid-base activity and the classroom discussion about different pedagogical examples, they realized the divergent use of scientific practices. They expressed that BRH helps the teacher to a better and organized lesson plan.

Ten of the pre-service teachers were interviewed after the first phase of the course on the above-mentioned topics and before the workshops. Interviewees said that there is not a strict order to these practices. They also reflected the divergent use of SPs in their lab lesson reports. The following reflections indicate such an understanding:

Real world, explanation, data, activity, prediction, discussion and modeling are what we call scientific practices. The order of these steps can be changed and some steps can be omitted, based on the topics and the conditions of classroom.

Before planning our instruction, we didn't specify which scientific practice will be the first and which one is going to follow it. We only decide what we can do and which scientific practice we can use. While doing the activity everything became clear. BRH facilitates the understanding of the activities, planning and outlining the lesson.

I can say that these three sessions were useful for me to understand what BRH and scientific practices were. I realized in most of the activities we can use BRH. The components do not follow a sequence and we can start from any point. For example, while conducting an experiment we can start from the real world and while conducting another we can start from prediction.

Two reflections in reports written after a lab session reveal the students' growing understanding of SPs:

There are various scientific practices and each of them can be a part of our lesson. There are also some relationships between these scientific practices.

I learned the following scientific practices in this course: Explanation, activity, data, real world, prediction, model and discussion/argumentation. We learned these practices and their interrelationships with each other and how to use these in our lab lessons effectively.

Another of the pre-service teachers stated on her reflection:

Before three sessions, which are related to scientific practices, I supposed that scientific practices such as activity, explanation, and modeling can depend on each other. In addition, I think these practices are shaped step by step and places of scientific practices cannot be changed. After three sessions, I understand that scientific practices are like benzene heuristic. These cannot depend on each other. Scientific practices used in activity can be changed according to topic, age of students and level of students.

After they had learned about BRH as a heuristic, I was expecting all the students to show all the components of SPs in some form of circular representation. Nevertheless, at the end of the treatment, only one person retained the concept of a linear sequence of SPs - 'Problem (or question), observation, recording data, prediction, and communication.' The change in the students' thinking about SPs shows that the intervention had had a positive influence.

Domain specificity

The following excerpt from a student's reflection touches on the concept of domain specificity:

In physics, experiments are more widely used than in biology. In biology, for example, evolution depends on modeling. There's no chance for experimentation. However, physicists can establish systems by answering questions of how the universe exists, the origin of matter, etc., and make experiments.

However, I realized that my students still did not understand domain specificity in science. One student, for example, revealed his confusion during a post-interview:

In physical sciences we construct hypotheses and make experiments and measurements and record these measurements to prove the hypotheses. There is also a social certification process. However, in social sciences, e.g. we make experiments on human beings. There is no need to use any tools.

His explanation reveals a lack of understanding. For this reason, I thought that I should emphasize the issue of domain specificity in subsequent lessons.

The epistemic components of SPs

Nine out of ten interviewees identified discourse/communication/discussion as components of SPs during post-interviews. One interviewee said that before the workshops, she had never thought about the significance of social certification in science. In contrast, another student, thinking about social certification after a lab lesson, wrote:

> *In order for your practices to be considered in scientific enterprise, it has to be approved by other scientists, so scientific practices have to include social certification.*

Such results led me to believe that my students had benefited from the workshops. The following quotation is from one of my own reflections, written after the first session of the intervention.

> *The high number of concepts that the participants used surprised me. During the interviews, the interviewees listed very limited number of components of scientific practices. However, the participants in this session used most of the components of the scientific practices in the concept maps they made. They used most of the concepts of scientific practices, but 3 groups mentioned curiosity and 4 groups included the component of asking questions in the concept map they made in addition to the concepts in BRH. One group used the concept of argumentation in the concept map they made. When we ask where they heard it, they told that they remembered it from the model they made individually during filling the questionnaire.*

The next reflection was written after the second session of the intervention. It shows that my students had begun to understand BRH and SPs in general.

> *This session was designed to help pre-service teachers adapt BRH to lesson planning. The students knew how to design a lesson plan. For this reason, they didn't have any difficulty drawing an outline of a lesson plan. The explanations they made about scientific practices, which the students may use in this lesson plan, showed that they gained a general understanding of scientific practices and BRH.*

After the workshops, all the students identified and discussed the SPs they had used in their LPs. I was glad to see that they emphasized the real world as a component of SPs, indicating that they understood that science deals with real-world phenomena.

After the third workshop, I concluded that I should put more emphasis on modeling:

> *It is interesting that although the participants in each section used most of the scientific practices in the activities they designed none of them used models even though they knew that it is one of the scientific practices. This situation made me think that we should emphasize modelling more in science teaching courses.*

Subsequently, one of the second author's reflections records an improvement regarding students' use of modeling in their LPs.

> *They were required to use BRM in their second microteaching performance. Most of the groups used modeling, as it is included in BRM and it is new for them, which was because they used to think experiment as the only way for a scientific activity. When comparing the two-microteaching performances, they were more organized by using BRM in the second performance.*

We found that the students used and discussed modeling in their second LP. Differently from their first LP, eight out of ten groups included modeling among the practices they preferred to teach. The following example from a LP about light and sound refers to an activity in which modeling was used in one of the second microteaching sessions.

> *Describe how you make sound from your materials (Materials: Plastic plate, box, tack, packet, rubber band, bead, colorful rope, 2 bottles, toilet paper roll, sellotape).*

The following quotation is taken from the report of the LP of this group:

> *For these microteaching sessions we chose three musical instruments as models and discussed what we would need to produce sounds based on the range of vibrations and frequencies of these instruments.*

The example of the model of the instruments is presented in Figure 3.

Neither the group that taught a lesson about extracting DNA by using simple household materials nor the group that taught about chemical and physical changes employed the SP of modeling in their microteaching. However, two members out of the three who had taught about DNA reflected that they would include modeling in their lesson were they to teach it again. The reflection written by one of these two students indicates an awareness of the importance of modeling.

> *If there would be more time than we had, another activity that is observing DNA samples on microscopes*

Figure 3 Example of modeling in microteaching hours.

can be added. Afterwards, students would draw the picture of what they would see and this could be considered as modeling.

When listing SPs during their interviews, pre-service teachers mentioned modeling more frequently after the workshops than they had before, and they incorporated modeling into their microteaching lessons. Seven out of ten groups included modeling in their LPs. On the subject of modeling, one student wrote:

I thought that modeling is waste of time before this course, because I didn't believe that my students could be creative in this way. My opinions changed after this course, because we saw some examples of experiments including scientific practices.

Two other students wrote:

If I do same task now, I would add some practices like prediction and modeling. I would ask students to drop iodine in to egg and milk and ask "What do you observe? Do you predict any color changes?" I would ask them to draw a rectangle and different types of food (i.e. fruits, vegetables, chocolate, milk-product, meat, bread etc.) and identify which are healthy and unhealthy.

If I do the same task now, I would include modeling in my instruction. I would construct a three-dimensional shape of a protein molecule.

The following reflection reveals a deeper understanding of scientific processes by mentioning the literature search as a source of discovery.

I would add a review of other scientific studies if I do the same task now because it may help students to understand the progress in information about buoyancy of liquids. We may also discuss the validity of the principle of Archimedes. Other studies that are done by other scientists may also give a different point of view.

Despite such improvement in my students' understanding of scientific processes, some of them still seemed to be confused about the nature of experiment. One student gave the following explanation during a post-interview.

Experiments should include measurable variables, as we learned from the course. Activities are easier things to entertain the students. However, observing the lens of the eye, well it may be disgusting for them, but it's a more sophisticated task. It can be regarded as an experiment. There's not any measurable thing here. It becomes an experiment as it gets complicated. There was nothing to be measured but I think measurable things can be added. Actually I don't want to say that the activities cannot be measured and experiments can be measured. They are a continuation of each other".

This pre-service teacher seems to be very much confused. He distinguishes activities and experiments by explaining that activities are entertaining, while experiments are more challenging and entail some form of measurement. I decided that we should discuss activities in general and experiments in particular.

The cycle in BRH

All the students identified and made use of the components of BRH in their LPs. This result convinced me that I can use this heuristic for the purpose of teaching SPs. One student wrote:

I think these practices make a lesson easier according to both the teachers and the students. Because the teachers know what or how they teach or what they make emphasis by using practices. Also the students understand the topic because the teachers follow the steps of scientific practices. I infer, myself, that scientific practices are really useful and beneficial for both students and the teacher.

Despite the usefulness of this heuristic, these pre-service science teachers neglected discourse and social certification in their representations of the scientific process. Although they listed discourse/communication/discussion in SPs during post-interviews, they seem to think of discourse and social certification as 'sharing results' and not as cooperation among scientists during the investigative process. Actually, the drawing of BRH seems to have confused my students about discourse and social certification. The directions of the arrows in the middle of the heuristic, intended to show the resemblance of the electron cloud and social certification, may have caused the misconception. The following reflection records my perception of the confusion.

The lesson started without any problems and I didn't encounter any obstacles until I introduced the pre-service science teachers to the BRH. After we discussed the BRH in the classroom I asked the students to link the ideas in the model to the acids and bases activity that they had just completed. Some students mentioned their confusion about the circle in the center of the hexagon. They thought that the arrows of the circle had a sequence and moved in a clockwise direction. I had never thought of this probable misconception arising from the model. At that moment the coordinator of our project (who was observing) interrupted the instruction and clarified the representation of the model by explaining the analogy of the electron cloud of the benzene ring and the circle in the model. From then on there was no question about the model in the participants' mind. In the second section I was careful to avoid this kind misconception.

The second author's reflection points out the same misconception about BRH:

The students defined the heuristic as having a continuous relation and this relationship specifies the format of instruction. However, some students were confused about the components of the model and had difficulty applying it to the activity. Some of them considered the components as sequential and didn't pay attention to the components in the center of the hexagon.

During the post-interviews, two pre-service teachers described their readiness to use the BRH for designing a LP. However, they also expressed confusion about the circle in the heuristic. I think that one can avoid this confusion by drawing the arrows in two directions. Despite the confusion, I think the heuristic was useful in stimulating discussion, and what I learned I used in subsequent lessons, during which I emphasized the bidirectionality of the arrows.

Ethics and utility

The interviewee who said in her pre-interview that one feature of SP is to follow the proper ethical rules did not say anything about ethics during her post-interview. Another student in the post-interview showed some misunderstanding of the role of ethics SP.

At the beginning science is not concerned about ethics. However, after encountering some problems like nuclear events… people asked questions, rightly, such as "Will you make nuclear weapons?" or about cloning, "Why do you do that?" These practices can harm people. Afterwards science began to be concerned about these ethical issues.

This statement implies an opinion that scientists neglect ethical issues while asking scientific questions and consider the ethical implications only after some problem has emerged. She had already conveyed the opinion that the goal of science is to be useful to people. Perhaps this opinion led her to the conclusion that scientists sometimes fail to consider ethical issues at the beginning of their work and later have to confront the ethical consequences. In total, only three students raised the question of ethics; nevertheless, their opinions are worth noting.

Students as scientists

From the beginning of the semester, we have been discussing the benefits of inquiry-based activities by which students 'develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world' (National Research Council 1996). However, I learned that my students did not all adopt this view.

The following is my reflection after the third session. It records my perception of the conflict among these pre-service teachers concerning the students' role in learning science.

This session aimed at helping the pre-service science teachers to discuss scientific practices that can be used in various lesson plans employing different pedagogical strategies.… In the morning session the participants discussed their plans regarding pedagogical strategies and scientific practices in lesson plans. Basically, two different views arose from the discussion. One group thought that lab sessions should be designed so that students would be active and the teacher would be a guide. The other group maintained that a primary grade student cannot design his/her own procedure without a teacher's input. This conflict between the two groups lasted until the end of the session. However, one participant agreed *with neither of the two groups. She argued the necessity of creating opportunities for students to discuss their own ideas and to make decisions but added that the teacher should also give explanations during lab sessions.*

I witnessed a similar conflict when the students were drawing concept maps after the workshops. Two discussed the students' role in learning. One young man claimed that students are little scientists, but his teammate opposed him. She thought that the students should discuss their arguments after their predictions, activities, and data gathering, and then should explain their results. He agreed with her except for the addition of a 'peer review experience'. He came up with the idea that students should have to explain and review their data before discussing their arguments just as scientists do, because the students are little scientists. However, his teammate found this view ridiculous. They did not resolve their differences and decided to show both views in their concept maps.

The discussion between these two students was audiotaped as they worked on their concept maps. Here is an excerpt:

P1: Don't they (the students) have a discussion like scientists?

P2: I mean, let's plan this like a science teacher conducting an activity in the classroom.

P1: Okay. But students should discuss their results with each other. And this time his/her friend becomes another scientist. I think this is very important.

P2: I don't agree with the idea that students become scientists when they discuss their results. I think we should draw two different ways after this point. I think it is ridiculous; you are creating a lab activity. Does a student's friend become a scientist?

P1: Yes, of course, a little scientist.

One of the goals of science education is to enable students to engage in scientific tasks just like scientists investigating the natural world. For this reason, one might think of students as little scientists, as one of my students advocated. However, his classmate repudiated this view. I suspect she would not appreciate the process of peer review in lab sessions. As for my point of view, I think I should give more time for discussion of the students' role in the science classroom.

Conclusions

With an 'auto-ethnographic gaze' as I 'zoom backward and forward, inward and outward' (Ellis 2004, p. 37) between my students and myself throughout this process, I can say that I as a teacher benefited from the course. As it progressed, I learned how to help these pre-service science teachers to a more comprehensive understanding of SPs and a better understanding of each epistemic component of SPs by acting as a 'complete member researcher' (Anderson 2006, p. 378). However, despite the benefits derived from their feedback and discussions of the BRH, I did not successfully teach them about domain specificity, ethics, and utility in science - or how to treat their students as little scientists. More time can be allocated for discussion of these issues in the future. One semester may not be enough to do justice to all the issues that have arisen in this course. Some I will take up in a second semester course (to be taken by the same students), which will concentrate on the NOS.

Considering my subjective experience as a researcher (Hamilton et al. 2008), I have decided to start this course next year by asking students to draw a concept map of SPs, thus their prior knowledge of SPs, and then to go ahead with the three sessions discussed here. During the lecture and microteaching hours, I will deeply discuss the concepts of experiment, observation, inference, and prediction in order to avoid any kind of misconception.

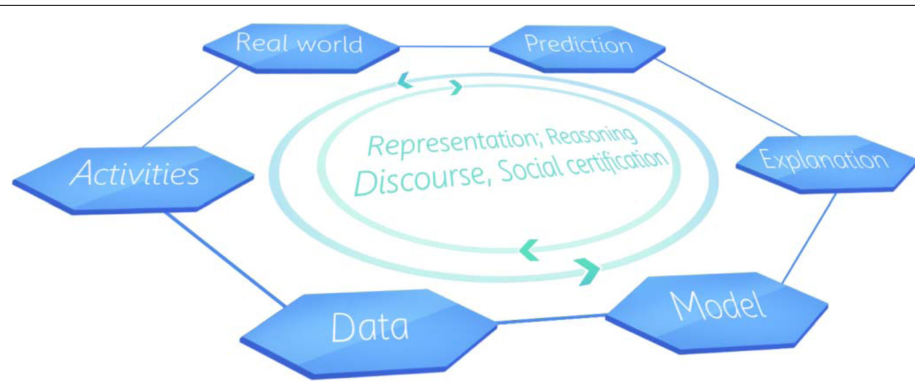

Figure 4 Updated version of the BRH.

After the first microteaching experiences, I will ask my students to reflect on their understanding of SPs in addition to their reports on LPs. Following their LPs, I will ask carefully constructed questions in order to hone the pre-service teachers' ability to ask high-quality questions that will help their students to engage in scientific tasks, just like scientists investigating the natural world. Then I will discuss disciplinary core ideas to increase students' understandings of domain specificity. Finally, I will focus on communicating information about social certification in science. Following the lectures, I will ask my students to focus on the quality of their questions, the core disciplinary concepts taught in their LPs, the ways in which their students will communicate information, and relevant ethical issues. After the second microteaching experiences, I will ask them to reflect on their understanding of the issues discussed during lecture hours. At the end of the course, I will ask them to draw another concept map of SPs to illustrate their newly acquired understanding of SPs and of science in general. This design for next year's course may help me to overcome the limitations of this study and lead me to a broader understanding of my students' ways of thinking about science.

To resolve the confusion caused by the arrow in the BRH, Erduran and Dagher (2014) enlisted a graphic designer to revise the diagram. This version of the BRH may better contribute to a holistic understanding of SPs and clarify the role of cognitive components such as representation and reasoning and social components such as discourse and social certification. Figure 4 shows the updated version of the BRH.

In summary, the cultural component of this autoethnographic study (Ellis 2004) was the interaction with my students, which led me to believe that the course as I designed it contributed to their holistic understanding of SPs as well as their understanding of each specific component. However, integrating SPs by using the BRH in explanations of lesson planning also helped me to see their misconceptions regarding domain specificity, ethics, the utility of SP, and the role of the students in learning science. Awareness of their misunderstanding may lead to continued improvement of my teaching.

Additional file

Additional file 1: Appendix 1.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
DS conceived of the study, and participated in its design and coordination and helped to draft the manuscript. GC participated in the construction of the theoretical background and the design of the study and the collection and analysis of data. Both authors read and approved the final manuscript.

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