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5. EPISTEMIC PRACTICES AND SCIENTIFIC PRACTICES IN SCIENCE EDUCATION

INTRODUCTION: STUDENTS' PARTICIPATION IN THE EPISTEMIC GOALS OF SCIENCE

There is a growing consensus in considering that learning science involves students' participation in the epistemic goals of science (Duschl, 2008; Kelly, 2008) or that, as Duschl (2008) proposes, science education should balance conceptual, epistemic and social learning goals. By epistemic goals we mean goals related to how we know what we know, to how scientific knowledge is constructed. Thus for instance understanding the criteria for evaluating explanations, theories or models, or the criteria for choosing one explanation over alternative ones. The main argument of this chapter is that these purposes may be achieved through placing scientific practices at the centre of science teaching and learning, in an approach that pays attention to their epistemic and social dimensions, besides the conceptual ones. This would mean shifting the focus towards the development and modification of epistemic claims (Duschl & Jiménez-Aleixandre, 2012), of claims related to scientific knowledge, in a perspective conceptualizing epistemic cognition as a practice (Kelly, 2016).

The chapter discusses, first, characterizations of epistemic cognition and epistemic practices, as well as the relationships between scientific and epistemic practices; second, characterizations of scientific practices and the translation of these theoretical approaches to policy; third, how to support students' engagement in the practices of modelling, argumentation and planning and carrying out investigations.

EPISTEMIC COGNITION AS A PRACTICE

We may say that the purpose of epistemic practices is to generate knowledge about the world. Epistemic practices (EP) are characterized in a variety of ways. For Kelly (2008) they constitute particular social practices, which are "patterned set of actions, typically performed by members of a group based on common purposes and expectations, with shared cultural values, tools and meanings" (Kelly, 2008, p. 99). He defines epistemic practices as "the specific ways members of a community propose, justify, evaluate, and legitimize knowledge claims within a disciplinary framework" (ibid, p. 99), and distinguishes three types within them, associated with producing, evaluating and communicating knowledge. Drawing from a sociocultural

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perspective and the notion of learning through participation in activities, Kelly (2016) conceptualizes epistemic cognition as a practice, proposing that epistemic practices are constructed in social interaction, and that they include interactionally accomplished understandings of knowing. According to Wickman (2004), who shares this sociocultural, situated cognition approach, epistemic practices reveal students' underlying *practical epistemologies* or epistemologies used in specific practices. This perspective focuses on practical epistemologies as actions, rather than as beliefs, considering that students' and teachers' *actions* are situated in an activity.

A complementary perspective, grounded on philosophy and psychology, is the AIR (Aims, Ideals, Reliable processes) model, developed by Chinn, Buckland and Samarapungavan (2011). Chinn et al. characterize epistemic cognition in terms of aims, standards and criteria (ideals), and reliable processes for attaining epistemic achievements. In this model, epistemic aims are goals related to finding things out, understanding them and forming beliefs. As Chinn et al. note, knowledge is the most discussed epistemic aim. Standards and criteria relate for instance to the specific standards people use to evaluate knowledge claims, or to select evidence. Standards may refer also to the consistency of a belief or knowledge system. The third component concerns the cognitive and social processes by which knowledge and other epistemic aims are achieved.

The appropriation of criteria for justifying knowledge or for revising models is a relevant component of epistemic cognition. Duschl (2008) argues that an understanding of criteria for evaluating knowledge claims, that is, deciding "what counts" (as evidence, as justification, etc.), is as important as an understanding of conceptual frameworks for developing knowledge claims. Duschl's conclusion is that conceptual and epistemic learning should be concurrent in science classrooms. He suggests a need for balancing conceptual, epistemic and social goals in science education, doing so by focusing on three integrated domains: (1) the conceptual structures and cognitive processes used when reasoning scientifically; (2) the epistemic frameworks used when developing and evaluating scientific knowledge; and (3) the social processes and contexts that shape how knowledge is communicated, represented, argued, and debated.

There are studies focusing on epistemic practices (EP), others focusing on scientific practices (SP), and sometimes these terms are used interchangeably. We think that, for analytical research purposes, it may be necessary to treat them as different notions, although there is a degree of overlapping between them, in particular in classroom contexts where they may blend. Students engaged in SP may be at the same time involved in EP, as discussed in the last section. Tentatively, we suggest that we can think of epistemic practice as a broader construct and of scientific practices as epistemic practices in the context of specific learning contexts or content areas. Figure 1 represents this overlapping. There are, however, some scientific practices – for instance measuring – which are not epistemic, and thus the overlapping is not complete.

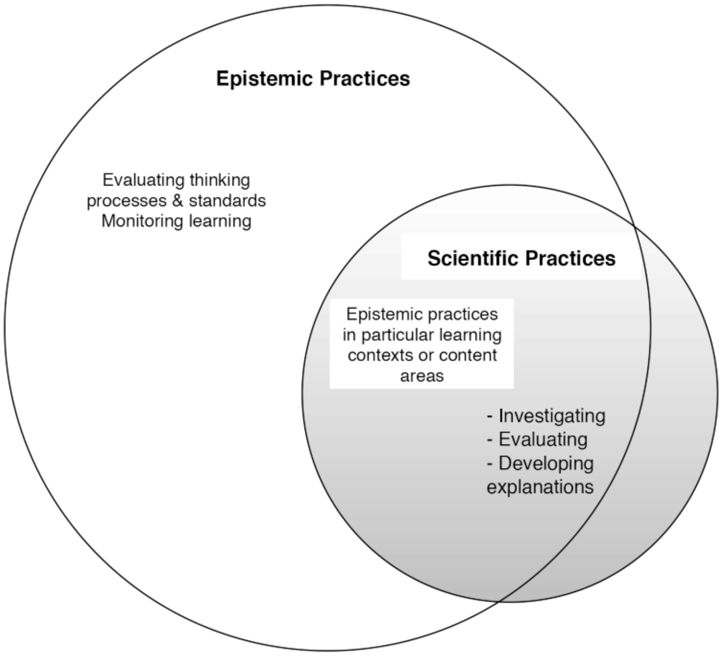

Figure 1. Relationships between epistemic practices and scientific practices

These perspectives represent a shift in focus from examining learners' epistemological beliefs, towards examining their engagement in epistemic practices. This change is translated into policy or evaluation documents. Thus for instance, the Program for International Students Assessment's (PISA) draft framework for 2015 (OECD, 2013) places as one of science education goals helping students to become scientifically literate citizens. However, as this framework acknowledges, scientific literacy requires not only knowledge about scientific concepts and theories but also about scientific practices and how they enable science to advance.

One of the aims of engaging students in scientific practices is to build knowledge about the nature of scientific endeavour, and about how knowledge is constructed; in other words to promote the development by students of an understanding of what scientists do (Osborne, 2011). The notion of teaching and learning sciences in a way consistent with scientific work is not a new one, it had been advanced by Dewey; what is new is the approach framing this participation as part of a coherent whole.

SCIENTIFIC PRACTICES AT THE CENTRE OF SCIENCE TEACHING

How can we promote students' participation in the epistemic goals of science? A way of achieving it is through placing scientific practices at the centre of science teaching and learning. Doing so would mean paying attention to the epistemic and social dimensions of science education, besides the conceptual ones. The notion of practices embodies a move "from viewing science as a set of processes to emphasizing, also, the social interaction and discourse that accompany the building of scientific knowledge in classrooms" (Reiser, Berland, & Kenyon, 2012, p. 8). For these authors, the practices involve doing the work of building knowledge in science and understanding why we build, test, evaluate and refine knowledge as we do. This is coherent with an approach that views science as consisting of a set of scientific practices (Osborne, 2014). Osborne's argument is that science education needs to include "explaining how we know what we know or why we believe what we do" (Osborne, p. 580), for doing so will contribute to a commitment to evidence as the epistemic basis of beliefs. He considers this commitment as one of science major contributions to contemporary culture, one that promotes rationality and critical thinking.

The Role of Activity and Purpose in Practice-based Approaches

It needs to be emphasized that a defining feature of scientific practices is *activity*. Students should be *engaged* in scientific practices, *carrying out* modelling, argumentation or investigation. It is also an engagement in discourse and social interactions, rather than only in experiments or hands-on. In his approach to epistemic cognition in practice Kelly (2016) proposes learning contexts where meanings are defined and socially negotiated around *purposeful activity*. Berland et al. (2016) offer a framework, the Epistemologies in Practice (EIP) for this practice-based approach to science education. The EIP seeks to distinguish students' reflective participation in constructing and evaluating knowledge from mere attainment of skills. For Berland and colleagues, "understanding science as participation in practices offers an explanation for these challenges: this perspective underscores that the work of science is part of an ensemble of activity such that the tasks are part of a coherent network of purposeful action" (Berland et al., p. 2). The EIP approach emphasizes two aspects of students' engagement in scientific practices: their epistemic goals for knowledge construction, and their epistemic understanding of how to engage in it. We agree with these authors in the relevance of purpose and purposeful activity in science education at all age levels. Monteira and Jiménez-Aleixandre (2016) discuss the role of active purposeful observation in kindergarteners' engagement in the scientific practice of using evidence. In the context of kindergarten they define it as prolonged systematic observation that has a clear focus, is guided by the teacher, recorded, explicitly discussed, and used to test claims and to revise initial models.

Scientific Practices in Policy Recommendations

The practices approach is being translated from science education research to policy documents, namely the National Research Council (NRC, 2012) framework and the New Generation Science Standards, NGSS (Achieve, 2013) in the U.S., which propose that science education be built around three dimensions: scientific and engineering practices, crosscutting concepts, and disciplinary core ideas. These suggestions, grounded on the idea that science requires both knowledge and practice, are framed in studies documenting that students' understanding of science and their competency in performing scientific investigations require understanding the specific disciplinary practices of science. This chapter focuses on the dimension of scientific practices. As the NRC framework acknowledges, the term *practices* instead of others such as *skills*, emphasizes that engagement in scientific inquiry requires coordination of skills with knowledge specific to each practice. It also emphasizes that students should *engage* themselves in the practices rather than merely learn about them. According to the NRC, the advantages of a focus on practices are that it avoids first, the tendency to overemphasize experiments over argumentation, critique or modelling; second the tendency to teach procedures in isolation from science content. It also promotes the acknowledgement of the existence of a broad spectrum of methods, rather than one single "scientific method".

The NRC (2012) framework frames scientific and engineering practices in three spheres of activity: Investigating, evaluating and developing explanations and solutions. Osborne (2011; 2014) provides a rationale for that model grounded on psychology and philosophy.

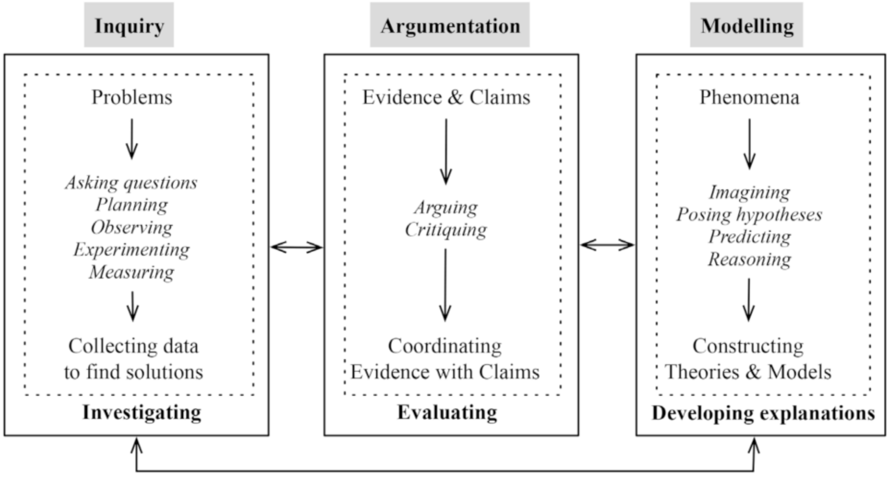

Figure 2. Three broad practices of scientific activity (modified from NRC, 2012)

Figure 2, based on the NRC (2012) framework represents how the three spheres of science are interrelated. In this modification we have associated the three domains or spheres from NRC (in bold at the bottom of each box) to the three scientific competencies (in bold over each box) from the PISA 2015 draft framework

(OECD, 2013): Evaluate and design scientific inquiry (inquiry), interpret data and evidence scientifically (argumentation), and explain phenomena scientifically (modelling). We propose that these three PISA competencies correspond to the three broad practices or spheres of science in the NRC. Operations making part from each practice are summarized in italics, and we have introduced some new ones in order to be coherent with the nature of each practice. For instance "planning" is introduced in "Investigating" to be coherent with the practice of *Planning and carrying out investigations*. The main goal for the operations is listed in each domain: investigating in order to collect data to find solutions to problems; evaluating evidence, data and claims in order to coordinate them; interpreting phenomena and developing explanations in order to produce theories and models.

Thus the activity of science may be synthesized in three spheres or overarching practices:

- *Investigating*: which involves asking questions, identifying problems, planning and carrying out investigations, or analysing and interpreting data.
- *Developing explanations*: which involves posing hypotheses, interpreting phenomena, formulating predictions or constructing and using theories and models.
- *Evaluating*: which involves selecting appropriate evidence, contrasting explanations against available evidence, comparing alternative explanations and critiquing them, or constructing arguments from evidence.

The three spheres contain the eight scientific practices proposed by the NRC (2012) and reproduced in Table 1:

Table 1. The eight scientific practices proposed by the NRC (2012)

Asking questions and defining problems	Using mathematics and computational thinking
Developing and using models	Constructing explanations and designing solutions
Planning and carrying out investigations	Engaging in argument from evidence
Analysing and interpreting data	Obtaining, evaluating, and communicating information

These eight practices may overlap in some cases; they are intertwined (Bell et al., 2012), and are not carried out in isolation. In the next section we discuss examples of how to support student' engagement in them.

ENACTING SCIENTIFIC PRACTICES IN SCIENCE CLASSROOMS

How are scientific practices enacted in the classroom? According to Bybee (2011), when students engage in scientific practices "activities become the basis for learning about experiments, data and evidence, social discourse, models and tools, and mathematics, and for developing the ability to evaluate knowledge claims, conduct empirical investigations, and develop explanations" (Bybee, 2011, p. 38). Therefore school science programs need to actively involve students through investigations and activities, including hands-on, laboratory work and minds-on tasks. In this section we discuss examples of tasks designed in order to engage students in investigating, argumentation and modelling.

Investigating: Which Toothpaste is Ineffective in Preventing Cavities?

This laboratory task, designed for secondary school students, requires them to *plan and carry out an investigation*, in order to compare the effectiveness of two toothpastes for preventing tooth decay. An excerpt of the handout is: "A campaign aimed at preventing tooth decay was conducted in schools, giving students two brands of toothpastes (x and y). Soon after, it was found that students having brushed their teeth with one of the toothpastes had more cavities than students using the other brand. So, we need to find out which toothpaste does not prevent cavities in order to withdraw it from shops. *Design an experiment to find out which toothpaste is less effective*. To do this you can use clamshell pieces to simulate teeth and hydrochloric acid to simulate the environment created in the mouth after eating carbohydrates." The task required two 50-minute sessions, one for planning the experiment, and a second one to implement it. Table 2 unpacks some components of the three broad scientific practices enacted by 9th grade students (Crujeiras & Jiménez-Aleixandre, 2015).

These operations, empirically identified in our study, are aligned with the 5D components proposed by Duschl and Bybee (2014) for the practice of *Planning and Carrying out Investigations* (PCOI): (1) Deciding what and how to measure, observe, and sample; (2) Developing or selecting procedures/tools to measure and collect data; (3) Documenting and systematically recording results and observations; (4) Devising representations for structuring data and patterns of observations; and (5) Determining if (1) the data are good (valid and reliable) and can be used as evidence, (2) additional or new data are needed, or (3) a new investigation design or set of measurements are needed. The focus of the task is on investigating, but the three practices are intertwined.

Evaluating Knowledge: Argumentation in Socio-Scientific Contexts

Evaluating knowledge is a practice that plays a crucial role in building scientific knowledge. In science knowledge claims are contrasted with available evidence in order to be accepted. Argumentation is this process of knowledge evaluation, involving connecting evidence to claims through justifications (Jiménez-Aleixandre & Erduran, 2008), these last called "reasoning" by McNeill and Krajcik (2012).

Table 2. Scientific practices students engage in when performing the task. Legend: SP = scientific practice; I = investigating; M = modelling; A = argumentation

SP	*Operation*	*How is it carried out in the task*
I	Planning the investigation	To decide how to identify the ineffective toothpaste: • *Proposing samples, equipment and procedure*, for instance: a) To use three shells (one for each toothpaste, and one control), weighing them. b) To measure a small volume (e.g. 10 mL) of HCl in a test tube. c) To place each shell inside a balloon, and the balloon at the top of the test tube and dropping the shell into the acid (or other procedures). • *Recording data*, for instance: a) Once the shell contacts the acid and the gas release starts, to measure the time until the balloon stands up. b) To record time values. • *Selecting a criterion in order to identify the ineffective toothpaste,* as: the balloon that stands up sooner will be the one containing the shell washed with the ineffective toothpaste. • *Considering fair testing and reproducibility criteria*: To use equal volumes of HCl, and clamshells of the same weight in all the experiments; to repeat each experiment at least twice.
	Carrying out the investigation	• *Carrying out* the chemical reaction with each shell and measuring the time that takes to each balloon to stand up. • *Collecting experimental data and representing them* in tables and graphs.
M	Using theoretical models	• *Understanding and applying the models* of chemical reaction and inhibition processes.
	Using analogies and simulations	• *Understanding and applying the relationship between the elements used to simulate* tooth decay (e.g. clamshells and HCl) and their targets in the natural world.
A	Interpreting evidence	• *Deciding if the data collected are valid and sufficient* in order to identify the ineffective toothpaste. *Applying the criteria* to the data.
	Linking claims to evidence	• *Concluding* which toothpaste is ineffective in preventing cavities and *justifying* the conclusion in the light of the data.

Engaging in argumentation means not only comparing alternative explanations and selecting the one that best fits with evidence, but also critiquing the ones that are unsatisfactory.

There is a wealth of research papers about argumentation, and resources including learning tasks (e.g. McNeill & Krajcik, 2012; see also the resources section). Two instances, summarized in Figure 3, are part of teaching sequences (Puig, Bravo, & Jiménez-Aleixandre, 2012) about genetics and ecology.

1. How do you explain black sprinters' achievements in athletics?
Since the athletics world championship in Rome in 1987, when there were three white finalists in the 100 m, black sprinters took all the final positions in the Olympic and World Championships. There are different explanations to these achievements:

A) This is due to their genes
B) This is due to the influence of factors such as nourishment, training, etc.
C) This is due to a combination of A and B

Your tasks:
1) From the available pieces of information, choose which ones support A, which ones B, and which ones C.
2) Choose the best explanation and justify your choice based on the different pieces of information available.
3) From the pieces of information provided: Which ones do you think that constitute evidence and why?

(*Eight pieces of information are provided, in the booklet in www.rodausc.eu*)

2. Resources management in a bay
A small town on the seaside was hit by a hurricane. Afterwards, many people were homeless, their harvests destroyed, and most of their cattle was lost. Currently the main resources they have for surviving is a small bay, where several fish populations exist, including sardines, herring and salmon. You are a NGO team, sent in order to help the people in the town to manage the bay, so that it provides them with food for several months while their crops are able to grow again and cattle can be raised. *Your objective in this task is to decide how to manage the bay in order to feed the population for as long as possible*. You will need to arrange the most efficient way of using the fishing resources available, and to elaborate a plan, explaining how you would carry it out.
(*Four data sets are provided, in the booklet in www.rodausc.eu*)

Figure 3. Two argumentation tasks (Puig, Bravo, & Jiménez-Aleixandre, 2012)

Both tasks are authentic, socio-scientific, drawn from real life, and require coordinating scientific explanations, the models of gene-environment interaction in the first example, and energy transfer in ecosystems in the second, with complex data. Results from their implementation are summarized in Puig et al. (2012), showing the difficulties that students (and the public), experience in making sense of science news and in relating pieces of evidence to complex scientific explanations through justifications. Students need to engage in argumentation tasks in order to learn that practice.

Developing Explanations and Models: Epistemic Criteria for Good Models

This practice engages students in developing explanations and models about natural phenomena; about how does the natural world work, and why it works that way (Berland et al., 2016). Scientific models are based on evidence, and thus argumentation and developing explanations are related. Duschl (2008) represents the relationships between evidence and explanation in three steps or transformations: (1) selecting or generating data to become evidence; (2) using evidence to ascertain patterns of evidence and models; and (3) employing the models and patterns to propose explanations. As Duschl points out, in each transformation students need to make epistemic judgments about "what counts" as data, evidence or explanations.

The example about modelling means to illustrate the overlapping of epistemic and scientific practices in classroom settings. It is drawn from the work of Pluta, Chinn and Duncan (2011) in the PRACCIS project, which focuses on model-based reasoning. The tasks had as a goal the development by students of criteria for good scientific models, in other words, epistemic criteria. 7th grade students completed a series of model-evaluation tasks. In the first task they were presented with contrasting cases of models, for instance 12 representations of volcanoes including models, non-models and debatable cases, and they were asked to select the ones they thought were models and discuss their ideas with a partner, in order to think about what distinguishes a model from a non-model. In the second task, students were asked to compare seven pairs of models about familiar phenomena, and to consider several questions, some general as which model was better (or if they were equally good), and some more precise, for instance about purposes: "which of these two models is better if you want to explain…?". Finally, students individually generated and wrote six criteria about good models. The criteria were coded in three levels: (a) primary criteria, central to the practices of science, such as reflecting the explanatory goals of models, or the fit of models with evidence; (b) secondary criteria, which contribute to the epistemic aims of science, such as mentioning data; and (c) criteria that were vague or suggested misconceptions about the practices of science. The authors suggest the need for an emphasis on epistemic criteria in science instruction.

Pluta et al.'s study shows that students engaged in scientific practices, as evaluating models, may be at the same time involved in epistemic practices, in this case in developing epistemic criteria for good models. We consider this an appropriate implication for concluding our discussion of scientific and epistemic practices.

SUMMARY: SUPPORTING ENGAGEMENT IN SCIENTIFIC AND EPISTEMIC PRACTICES

- Learning science involves students' participation in the epistemic goals of science, goals related to how scientific knowledge is constructed.
- Science education's epistemic goals may be achieved through placing scientific practices at the centre of science teaching and learning.

- A defining feature of scientific practices is *activity*. Students should be *engaged* in scientific practices, *carrying out* modelling, argumentation or investigation.
- Science instruction needs to actively involve students in scientific practices through investigations, evaluation activities and development of epistemic criteria.

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FURTHER READING

ADI (Argument Driven Inquiry) web page. Downloadable instructional materials for argument-driven investigations. http://www.argumentdriveninquiry.com

McNeill, K. L., & Krajcik, J. (2012). *Supporting grade 5–8 students in constructing explanations in science. The claim, evidence and reasoning framework for talk and writing*. New York, NY: Pearson Allyn & Bacon.

NGSS (Next Generation Science Standards) Web Seminar Series, by National Science Teachers Association (NSTA) to help implementation in the classroom. http://learningcenter.nsta.org/products/symposia_seminars/NGSS/webseminar.aspx

PRACCIS (Promoting Reasoning and Conceptual Change in Science). Focus on model-based reasoning. https://sites.google.com/a/gse.rutgers.edu/praccis-promoting-reasoning-and-conceptual-change-in-science/

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