The Collective Production of High School Students' "Images of Science"

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Abstract: In the science education research literature, it often appears to be assumed that students "possess" more or less stable "images of science" that directly correspond to their experiences with scientific practice in science curricula. From cultural-historical and socio-cultural perspectives, this assumption is problematic because scientific practices are collective human activities and are therefore neither identical with students' experiences nor with accounts of these experiences that students make available to researchers. Drawing on data collected before, during, and after pre-university biology students' internships in a scientific laboratory we show how students' "images of science" are co-produced along a trajectory of translations that was determined by the use of particular actions and tools, and a particular division of labor in scientific practice.

Introduction

Coming to understand science involves gaining insights into a number of facets of science. There is knowledge of the contents and methods of science—that is, the laws, models, theories, concepts, ideas, experimental techniques, and procedures used by scientists. Such *knowledge in science* forms the basis of undergraduate science curricula. There is also knowledge about how scientists develop and use scientific knowledge: how they decide which questions to investigate, how they collect and interpret scientific data, and how they decide whether to believe findings published in research journals. This is *knowledge about the nature of science*. Here, we report students' views about the nature of science; their *images of science*. (Ryder, Leach & Driver, 1999, p. 201, last emphasis added)

Students' "images of science" have been monitored for more than a half a century now. The first studies were based on written tests administered on a large scale; in these tests, students were asked to write an essay in response to the somewhat loose question: what do you "think of scientist and science" (Mead & Metraux, 1957, p. 384). More recent studies have drawn on semi-structured interviews that specifically addressed issues concerning the nature of scientific inquiry (e.g., Ryder *et al.*, 1999). Whatever the kind of method, studies in this research field conducted so far draw upon the assumption that students "possess" more or less stable "images of science" that can be elicited and captured in some form; these images are thought to directly correspond to their experiences with scientific practice in school or out-of-school science experiences.

It recently has been found that students—when responding to questionnaires used to monitor their "images of science"—draw upon "different epistemological representations in different contexts" (Leach, Millar, Ryder & Séré, 2000, p. 497). More so, other empirical and theoretical work suggests that any elicitation of knowledge bears the mark of the context of elicitation; that is, the forms and contents of knowledge that individuals make available to each other depends on the situation and therefore is highly contingent (Roth & Lee, 2007). This implies a less stable and individual nature of students' "images of science" and, consequently, a looser correspondence with students' experiences with scientific practice in science curricula. Scientific practices are therefore *translated to* (rather than correspond to) students' "images of science"; and this translation, in its very nature, produces differences so that the original and the new no longer are the same. The purpose of this study is to answer the method-related question about how students' "images of science" are produced.

Theoretical framework

We conceptualized the practices and pathways supposedly leading to (intended) "images of science" as reported in the literature (see Figure 1). Broadly speaking, the pathway towards students' "images of science" as reported in the research literature follows the pathway 0 → 1 → 2 → 3 and overlaps with the curriculum pathway 0 → 1 that intends to lead to students' "images of science."

To better understand the processes of "imagification" on the pathway between scientific practice and students' "images of science" we use cultural-historical activity theory (CHAT) as an analytic tool. Cultural-historical activity theory is rooted in the work of soviet psychologists who maintained that human action cannot be understood outside actual praxis, which is conceived in terms of *object-oriented* and *artifact-mediated* activity (Vygotsky, 1978). Cultural-historical activity theory is concerned with understanding real, concrete activity in the very settings where it occurs, based on the grounds individual and collective human agents have for doing what they do (Roth & Lee, 2007). Activity theory therefore aspires to understand and explain each form of action in its concrete material detail (artifacts, objects), whatever the situation. It allows us to analyze in detail practices conceptualized in Figure 1 and how "images of science" arise there from.

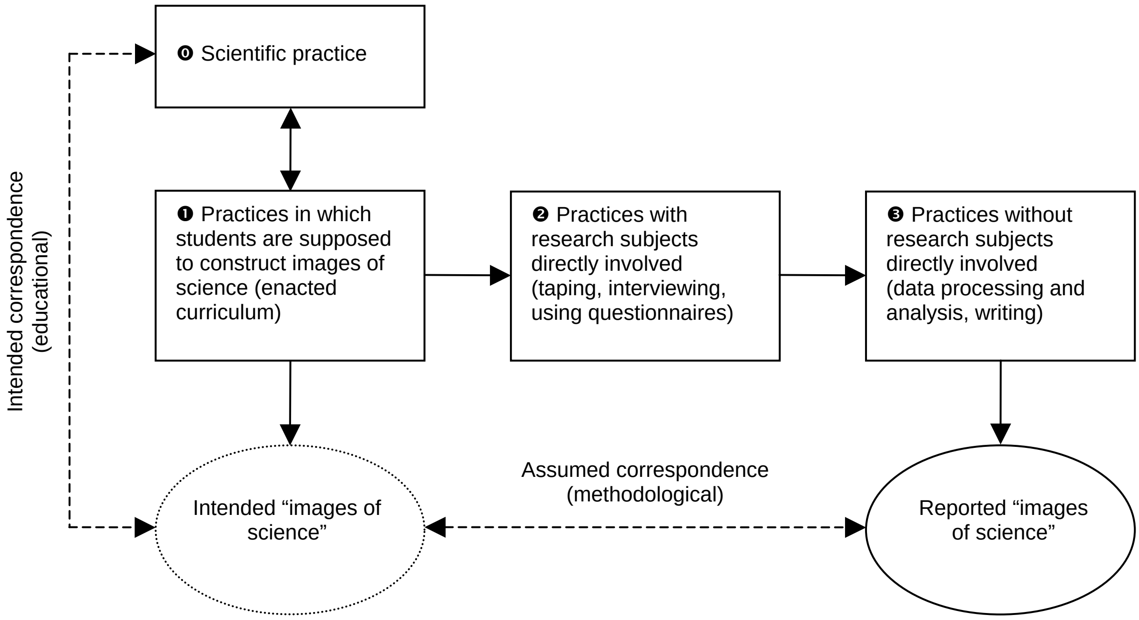

Figure 1. Distinguished practices and pathways supposedly leading to (intended) "images of science" according to the literature.

Design

We conducted an ethnographic study of student internships in a science laboratory after which we interviewed students about their "images of science." Thirteen eleventh-grade students attending a public urban high school enrolled in the internship as part of an honors biology course. The scientific laboratory investigates the environmental parameters of drinking water supplies and its members include the chief scientist, a laboratory manager, scientists, postdoctoral fellows, technicians, and graduate students. After meeting with the scientists and technicians, students actively arranged their after-school time to be able to participate in the scientific laboratory.

As part of our research program on learning about science in school and authentic scientific settings, we conducted a ten-month ethnographic study of the scientific laboratory, during which the internships started after six months. Data were collected by means of videotape, field notes, (scientists, technicians), and by collecting artifacts. After the internships, we held semi-structured interviews with the students about their "images of science," for which we applied interview probes that were used in other studies and reported as fruitful for the aim (Ryder *et al.*, 1999). All interviews were videotaped and the resulting movies were transcribed.

Students' "Images of Science"

We conducted a coarse-grained analysis of the transcribed interviews according a method described in earlier studies (Ryder *et al.*, 1999). The aim of this analysis was twofold: (a) to compare our data with that of others who provided students' "images of science"; and (b) to provide an impression of students' "images of science" as they can be constructed based on the data we collected. The method we applied codes the data in three dimensions: (a) students' views about the relationship between scientific knowledge claims and data; (b) students' views about the nature of lines of scientific enquiry; and (c) students' views about the social dimensions of science. Table 1 presents the outcomes of our findings as well as comparable data from the study we adopted our coarse-grained analysis from.

There are some noteworthy similarities and differences between our data and that of the other study. To begin with, the outcomes of the relation of scientific knowledge and data reveal a comparable pattern. In both groups, the students indicate that knowledge claims are provable while fewer students indicate that knowledge claims go beyond the data. Further, in our study, it appears that students more often referred to an external location to in explaining how a scientist decides what research questions to investigate. This probably is due to the nature of the scientific research the students were engaged in. In our case, the students were engaged in drinking water research, which has many practical, external applications and is publicly significant, and which was repeatedly pointed out to the students. The students in the other study were involved in several scientific laboratories, some of which may be less explicitly in explaining the external applications to the students. Finally, in our study, students less frequently referred to a scientific community, but more often to individual scientist and the institutions of science in answering questions about the nature of science. Again, this may have to do with nature of the internships. The students in the other study worked a longer period of time (up to 8 months) together with one scientist. During this time, they have more opportunities to experience that the scientist is part of a community. In contrast, in our study, the students worked a short period (two months) in close collaboration with a technician who was during the time of collaboration not collaborating with other scientists.

When adopting the method of the larger study, our data would also allow the claims that (a) "students in our sample tended to see knowledge claims as resting solely on empirical grounds, although some students mentioned social factors as also being important" (Ryder *et al.*, 1999, p. 201) and (b) "issues relating to scientists working as a community were underrepresented in the students' discussions about science" (p. 201). However, the differences between both groups show that contexts are likely playing a role here, which is the very reason for this study, that is, a deeper analysis of the translations of scientific practice to students' "images of science" in these contexts. After conducting this first analysis, we had a sense that there was more to our data sources and that these course-grained analyses actually distorted what we had come to understand through our extended participation in the laboratory, classroom, and meetings with students. We therefore decided to conduct a fine-grained analysis.

Table 1. Students' "images" of science according to the methods of Ryder *et al.* (1999).

		Category	No. of students making statement of each type (N=11)	
			Our study	Ryder *et al.*, 1999
A	Relation scientific knowledge claims and data			
	Aa	Knowledge claims as description	2	2
	Ab	Knowledge claims as provable	9	11
	Ac	Knowledge claims go beyond the data	2	4
B	The nature of lines of scientific enquiry			
	Ba	Location in individual interests of scientists	4	10
	Bb	Internal location in epistemology of discipline	7	10
	Bc	External location	8	4
C	Students' views about the social dimension of science			
	Ca	Individualist view	7	1
	Cb	Recognition of community of scientists	1	8
	Cc	Recognition of institutions of science	8	7

Interpreting Translations of Scientific Practices: Description of Analysis

The objective of the fine-grained analysis was to exemplify the role of translations in the production of students' "images of science." The analytic method is grounded in cultural-historical interpretations of human activity (e.g., Roth, Hwang, Lee & Goulart, 2005) especially as it pertains to science (e.g., Roth & Breuer, 2003). We aimed to identify participants' accounts of the lived experiences of scientific practice that are transferred to and used in other practices, such as terms that stand for particular tools and actions. Thus, we focused on *boundary objects*. These objects are in this case particulars of "scientific practice" that are transferred to other practices and hence are generalized (Gieryn, 1983; Latour, 1987).

Our videotapes from the ethnographic case study and from the interviews therefore provided us with natural protocols with students' and scientists' translations of the scientific practices in which they engaged. We analyzed our database both individually and collectively, following an interdisciplinary method of involving groups of researchers in the analysis of interactions (Jordan & Henderson, 1995). The data sources provided us with critical moments that exemplified the role of translation in the production of students' "images of science."

We randomly accessed interview transcripts and focused on excerpts in which students described scientific practices they were engaged in. We picked out terms and concepts describing scientific practices and compared these with the ethnographic data. We thusly identified boundary objects by which participants described scientific practice and that appeared both in the interviews and the ethnographic case study. For instance, one of the participants, Carey, referred to a particular technique (tool) called "Bacterial Source

Tracking" while describing scientific practice. This is a common laboratory technique in which bacteria uniquely found in human and animal excrement (in this case *Escherichia coli*) are used to track fecal pollution to its human and/or animal source (Meays, Nordin, Broersma, & Mazumder, 2004). As we show in more detail in the next section, this technique became a relevant boundary object because each of the translations was associated with this object and we could track it back in each of the data associated with it. More so, with each transfer from one practice to the other along the trajectory from scientific practice to Carey's "image of science," the meaning of the technique was *translated* and *changed*, which is a characteristic of boundary objects generally (e.g., Fujimura, 1992). By tracking back such boundary objects, we could identify how scientific practice was translated to students' "images of science."

The collective production of "Images of Science"

In this section, we exemplify the role of translation in the production of students' "images of science." This exemplification is presented as a narrative, starting with exemplary data from students' interviews in which they virtually made their "images of science" available and tracking back towards scientific practice. We show how students' "images of science" were co-produced along a trajectory of translations which was determined by the use of particular actions and tools, and a particular division of labor in scientific practice.

Episode 1: Students explaining scientific practice to educational researcher

In this episode, we focus on the interviews after the internships. We show how students translated to us their lived experiences of scientific practice to accounts of particular actions and tools, and therewith provided data for the construction of objectivist "images of science."

In the following excerpt, the interviewer, Michiel, refers to the chief scientist's "scientific research," (line 01) which "aims at certain questions" (line 02). Then he asks why the chief scientist "wants these questions to be answered as part of his research program" (lines 03-04).

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Michiel:  Okay, now during the last weeks you did scientific research in the lab of Dr. MacArthur. His research aims at certain questions. Why do you think Dr. MacArthur want these questions to be answered as part of his overall research program?
Carey:    Why does he want them answered?
Michiel:  Yeah these type of questions?
Carey:    I guess just to make, like for ours we did Bacterial Source Tracking, just to make things a lot easier almost.
Michiel:  To make things?
Carey:    Easier.
Michiel:  What do you mean with easier?
Carey:    Instead of taking a water sample and taking samples from hundreds of different animals you take the water sample and just related it to the animal – making the steps shorter in the process. Is that what you were asking?
Michiel:  Any reason why the steps should be made shorter?
Carey:    To speed up processes.
Michiel:  But why does Dr. MacArthur want to do this? Make the steps shorter?
Carey:    Uhm… I don't know, we were never told why he wanted to. I guess maybe with shorter steps you can go further in research without having to do step after step. You can do a couple steps and go farther in your research without it being time consuming and it costs less money to further the research.
Michiel:  And where does that research lead to?
Carey:    Uhm, Nelly was saying that there was this place where you could place almost a temperature thing, you could place it in the water and it would read E. coli. That is what she was saying was the main main far far goal was.
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While explaining why the chief scientist wants these questions to be answered as part of his research program, we can observe that Carey refers to a tool, namely the "Bacterial Source Tracking" (line 07) technique she carried out with the technician in the laboratory. She further explains that she did this laboratory work "to speed up processes" (line 17), therewith referring again to laboratory procedures when explaining the aim of the chief scientists' research. Finally, Carey points out that this research leads to "almost a temperature thing, you could place it in the water and it would read *E. coli*" (lines 26-27). In providing these accounts of her lived experiences, Carey thus focuses rather on particular tools. More so, the aims of the practices she describes are at the level of the individual goals of the technician rather than the level of the entire activity because "they were never told why he wanted to" (line 19). Indeed, the "main main far far goal" (lines 27) of this part of the research program is to operationalize the technician's actions required for determining contamination of *E. coli* into a single tool that would be "almost a temperature thing" (line 26). This episode thus shows how "scientific research" (line 01) is reduced to one of its tools and inherent procedures and how Carey articulates its objectives hence at the level of actions (goals). As such, the tools and actions discussed here are generalized and therewith *stand for* scientific practice.

It is relevant to note here that Carey's accounts of lived experiences like the ones in this excerpt can be used as boundary objects to construct objectivist "image of science." For example, based on Carey's "temperature thing that would read *E. coli*" (lines 26-27), we classified her account of her lived experiences of scientific practice as "Aa" (Knowledge claims as description). Therewith, Carey's account of her lived experiences of scientific practice is translated to an account of an objectivist "image of science." This translation, in turn, is based on the premise that we are discussing "scientific research" (line 01) in the interview. However, the object of the interview is Carey's subjectivity (rather than scientific research as an object in itself), in which Bacterial Source Tracking is emerging as being identical with scientific research. To better understand how this "image of science" is produced we approach Bacterial Source Tracking as a boundary object and track it back to the practice from which it is transferred by Carey (during her transfer from the internships to the interviews as a boundary subject). There, we can observe its use in relation to the entire activity in which it emerged.

Episode 2: Students and technicians engaged in internships

In this episode, we focus on meetings in which students and technicians discussed what they were doing as part of scientific practice. A plenary meeting concretized the end of the internships. Here, the students presented their work to the entire laboratory personnel (scientists, technicians, graduate students, and so on) and the other student groups. The following excerpt is the introduction of the presentation of Carey's group, presented by the other group members, Cameron and Jack. We show how a particular boundary object has a meaning that differs from the meaning as articulated by students during the interviews.

29 Cameron: Alright so, I'm Cameron, this is Jack, and we pretty much did our project
30 on Bacterial Source Tracking. And we worked with Nelly and she was really
31 chill, we had a really fun time. Okay I need to warn you, there's a lot
32 of really kind a random funny pictures in here with like funny captions
33 so just bear with me if you don't think they're funny. And so, oh yeah
34 and Carey she's supposed to be here she went home in halfway but. Okay
35 so, pretty much yeah Nelly is our group leader, obviously from this
36 university, you guys probably know that. Okay so yeah we did Bacterial
37 Source Tracking, it was pretty exciting. Um yeah so the introduction,
38 okay yeah so this is just talking about we were working with *E. coli* and
39 uh trying to find out where the, the contamination from *E. coli* is coming
40 from like what from, from what animals and stuff so this is just some
41 information, I'm not really gonna read it. Well that's pretty much the
42 gist of *E. coli*. And [flips slide, laughs] antibiotic resistance testing
43 and that was really cool. I uh, was pretty excited, that was the first
44 big phrase I learned so I was, it was pretty exciting. So yeah that was
45 really exciting we uh took little cultures of uh *E. coli* and put little
46 tables of antibiotics on them to see um the area of (.) um (.) that word
47 (.) [snaps fingers] can't remember, where there's all the dead *E. coli,*
48 so how far it kills, how effective it is. …[?]… alright, take it over
49 Jack!
50 Jack: So uh
51 Cameron: Oh yeah, this is the one that's supposed to be at the end, so just shield
52 your eyes [laughter] okay! There we go.
53 Jack: Okay uh so next was um, this is the first thing.
54 Cameron: Yeah this is the first thing we did.
55 Audience: Okay your slides are out of order, guys.
56 Cameron: Just that one's out of order! The first one but that's okay. So the first
57 step we did was the filtration of the samples
58 Jack: Yup um, the yeah we had to filter it, take it isolate the *E. coli*, and
59 other bacteria, but we were only looking for the *E. coli* and they're
60 filtered through a .44 micrometer Millipore filter which allows the water
61 to pass through but the *E. coli* and other bacteria be held back.
62 Cameron: It was really hard to get the filters out of the little packages, that
63 was probably the hardest part. Sitting there like [makes getting-things-
64 from-small-packages motion] rrr.

Cameron introduces "Bacterial Source Tracking" (line 30), which is the boundary object that was identical with scientific practice during the interviews. In this episode, however, Bacterial Source Tracking does not appear as identical with scientific research. From students' accounts of their lived experiences, it appears that they were preoccupied with several actions and tools during the internships rather than the activity of scientific research: Getting "the filters out of the little packages" (line 62) and "antibiotic resistance testing" (line 42) were experienced as "probably the hardest part" (line 63) or "the first big phrase I learned" (lines 43-43). Indeed, with "we had to filter it" (line 58), Jack refers to the goal of the actions rather than the object of the activity. The meaning of Bacterial Source Tracking thus appeared to have changed with its transfer by the student from the internships to the interviews. This does not mean that the student suddenly assigned a different meaning to Bacterial Source Tracking. Rather, the activity had changed from internships to interviews and the latter are co-produced by both the interviewer and the student. During this activity, the meaning of Bacterial Source Tracking changed because the subjectivity of the students (rather than the object of the scientific research) became the object of the interviews and therewith these actions (rather than scientific research activity) became identical with scientific research. In turn, the students' experiences during the internships were the result of a co-produced activity: "we worked with Nelly" (line 30). To better understand this co-production and its resulting production of students' "image of science," we again approach Bacterial Source Tracking as a boundary object that was transferred from scientific practice by Nelly, the boundary subject.

Episode 3: Introduction of students to internships

In this episode, we focus on a meeting in which the students were introduced to the technicians work and therewith on the technician's subjectivity. We show that the meaning of students' accounts of particular actions and tools articulated during the internships differs from its meaning articulated by the technician. This change of meaning is the result of changed subject of the activity and hence a changed subjectivity. In the following excerpt, Nelly, the technician who was to work with Jack, Cameron, and Carey, introduces her work to the students.

Okay so as I said before, I'm Nelly. I'm working on Bacterial Source Tracking of *E. coli* in surface water. I'm working with a post-doc named Frank, and uh a senior researcher named Gerald so you'll get to know these people, don't worry about it. So bacterial source tracking is basically using genotypical and phenotypical uh characteristics of the, in this case, bacteria to basically determine where it came from and hopefully how it got there. Um genotypical analysis, basically DNA, phenotypical is basically its physical traits and in this case we are using antibiotic resistance. Which kind of piggybacks a little bit with what Curtis ((a fellow technician)) is doing. You'll get to know that. We all kind of piggyback off each other. So we've got unknowns sources that basically just come from water, random water samples. And we've got known sources, which come from scat samples so we can compare unknowns to knowns and hopefully be able to pinpoint what this *E. coli* came from. Um, so *E. coli* is a bacteria, I'm sure you've all heard of it before. It lives in our intestines and intestines of most warm-blooded animals. Um, and it's also found in the environment so basically, since it's found in the environment, it gets into our food, food gets into us, it lives in us, pretty straightforward. Um, you guys are probably too young to know about the Walkerton outbreak a couple of years ago but basically Walkerton, Ontario had a big *E. coli* contamination in their water and I believe something like 40 people was it died from it? Um, anyway, *E. coli* infection seriously not fun. Um, can be fatal, usually in the elderly or the very young. But it like attacks your kidneys and like very not fun. So this is what hopefully you guys will be doing. I'm gonna start off with some field sampling. Well, we won't actually be doing any field sampling but it's basically going and taking a sample of water. Pretty straightforward. So this, step 2 is where you guys will start. And we're just gonna filter it, throw in a uh, nutrient broth, which will differentiate between *E. coli* and other fecal coli forms. So little blue dots on that slide ((points to slide)), although they look kinda black there, um, those are *E. coli* other ones will be bright red, they're fecal coli forms, usually we get some white ones and we're still trying to figure out what they are. Um, then we're gonna start to purify. So by purifying it we're gonna purify, we're gonna take our blue *E. coli* culture, smear it all over a MacConkey plate, MacConkey again has another indicator in it which is gonna turn *E. coli* bright yellow which is the top plate ((in the slide)), so all that little bright yellow goop is actually *E. coli.*

In this excerpt, Nelly describes the boundary object, "Bacterial Source Tracking" (line 65). The meaning of the boundary object differs from the meaning articulated by the students in several dimensions. First, Nelly starts with introducing some people, "Frank" (line 66), "Gerald" (line 67), "Curtis" (line 72), as well as particular positions of people, like a "post doc" (line 66) and a "senior scientist" (line 66-67) that reflect a division of labor she also articulates: "We all kind of piggyback off each other" (line 75). The tools and actions for which Bacterial Source Tracking stands, is thus associated with a particular division of labor. Second, she illustrates the pathogenic characteristics of *Escherichia coli* bacteria, the object of activity, with an anecdote, the "Walkerton outbreak" (line 81). This can be interpreted as an effort to illustrate the motive of the scientific practice in which the students are about to engage and of which Bacterial Source Tracking is a part. During this introduction, Bacterial Source Tracking gets a meaning as something that is part of a bigger practice. Finally, in her introduction of scientific practice to students, she explains that they will only be engaged in a specific aspect of Bacterial Source tracking, namely "antibiotic resistance" (line 71-72) and of this technique they "won't actually be doing any field sampling" (line 86-87). Indeed, the phrase "antibiotic resistance" was also articulated by one of the students in the preceding translation and is as such also a boundary object. However, the relation between both boundary objects which is articulated here was not articulated by the students.

In this excerpt we can observe how the technician attempt to explain the relation between the specific set of actions that encompasses Bacterial Source Tracking and the activity of scientific practice in which she participates. The meaning of Bacterial Source Tracking is therewith a different one than the meaning articulated by the students. This change of meaning is the result of a changed subject of the activity and hence a changed subjectivity. This change subjectivity and inherent change of meaning is also observable in the different articulations of the filtering technique. Nelly articulated that "we're *just* gonna filter it" (line 88-89, emphasis added), while for the students this was "probably the *hardest* part" (see previous excerpt, line 63, emphasis added). In turn, Nelly's involvement with this project and the resulting collaboration with the students was also the result of a division of labor in the co-produced activity. By coupling students with technicians, students were mainly exposed to the technicians' tools (rather than the scientists' tools), which had a particular impact on students' accounts of their lived experiences of scientific practice. As boundary objects, these accounts would be transferred to the interviews. The division of labor in the laboratory thusly determined the particular translation of scientific practice in the production of students' "image of science."

Conclusions and implications

This study aimed to exemplify the translations of scientific practice that play a role in the production of students' "images of science." A coarse-grained analysis showed our data to be comparable with earlier reported "images of science" (Ryder *et al.*, 1999). A fine-grained analysis showed how students' "images of science" were co-produced along a trajectory of translations which was determined by the use of particular actions and tools, and a particular division of labor in scientific practice.

Given the outcomes of our case study, the current notion of "images of science" as knowledge attributed to individuals is inappropriate. Particularly, in this case, we have shown how students' "images of science" were the result of a co-production to which many individuals contributed as they engaged in collective practice. More so, inherent to the narrative we showed is a time-dependency of this co-production which is absent from students' "images of science." Arguably, due to the dynamic and contingent nature of this collective practice, the resulting "images of science" are stable only because of the given point of time on which they are fixed as text in science journals. Therefore, instead of students' "images of science," we propose to approach students' "images of science" as particular co-productions at a given point in time.

In many instances, students do not participate directly in scientific practices but engage in more "school-like" contexts in which scientific artifacts play a role, like science classes and labs or in museums, amusement parks or by using websites. Arguably, in these contexts, particular co-produced translations of scientific practice play an even more significant role, which adds another layer to the already stratified and collective nature of students' "images of science." When making their "images of science" available, students thusly draw on an ever-changing and increasing blend of experiences through each of which several co-produced translations of scientific practice are woven.

Older students draw on a wider range of experiences when making their images of science available (Driver, Leach, Millar & Scott, 1996). Yet, this increase of experiences does not necessarily lead to a greater correspondence between students' "images of science" and scientific practice. Because students' "images of science" are the result of a dynamic, multilayered, collective, and thus contingent process, the possible variations in experiences (translations) on which students draw when making their "images of science" available increases as well. This explains why valid and reliable assessment of "students' images" of science is so difficult (Lederman, Wade & Bell, 1998), if possible at all. On the other hand, science education is a political construct that favors particular "positive" translations of scientific practice (Jenkins, 2007), which biases the variation in the types of "images of science" (translations) that students will make available. This brings us to the educational consequences of this study.

The contingent nature of students' "images of science" implies that these entities are not stable at all. This is relevant for studies which considered the ways in which students' activities during project work are influenced by *their* "images of science" and vice versa (e.g., Ryder & Leach, 1999; Séré *et al.*, 2001). For example, in one of these studies, the authors "were interested in the knowledge students use in making decisions about how much data to collect, which of the data to use, and what can be concluded from the data available" (Séré *et al.*, 2001, p. 500). In their study, the authors by and large followed the pathway we outlined in Figure 1 to monitor students' "images of science." Based on this method, the authors claim that "students' reasoning has an epistemological and an ontological dimension, and that it often differs significantly from accepted perspectives on the nature of science" (p. 499). In the same study, the authors claim that individuals' responses across a range of questions could not be characterized by discrete positions about the respective role of theory and data in experimentation. Our conception of students "images of science" explains both findings as students' "images of science" obtained in the study are the outcome of a collective process rather than that it mirrors knowledge individuals "possess." For example, the epistemological and ontological dimensions that often differ significantly from accepted perspectives on the nature of science may be the result of a particular translation of scientific practices students were engaged in. According to our perspective, students' "images of science" are an outcome of a *network of activity systems* and of the passage of boundary objects between them. The "significant difference from accepted perspectives on the nature of science" is the result of the favor of particular translations of scientific practice in this construction process.

Our findings thus cast doubts on instructional practices that aim at the individual learning of particular "images of science" as well on studies that aim to validate such instructional practices (e.g., Bell, Blair, Crawford, & Lederman, 2003). Given their collective nature, an individual cannot "possess" those "images of science." The design and validation of instructional practices during which students articulate certain "accepted" "images of science" should thus be conceptualized as studies that make clear how certain translations of scientific practice are favored in collective practice. We doubt whether notions of students' "images of science" as individual cognitive entities can inform the broad aims of science education, such as the promotion of scientific literacy (De Hart Hurd, 1998). Rather, future research should focus on the question how science education can be transformed to a collective practice that favors translations less incommensurable with scientific practice. The development of this latter aspect of scientific literacy requires collective engagement in practices that are more or less identical with (rather than translations of) scientific practice (Roth, 2003; Van Eijck & Roth, 2007).

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