Formation of students' investigative expertise in the school science laboratory – a study of practical work in lower secondary school

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Summary: Work in the school science laboratory has been criticized for being pseudo-experimental, resulting only in a reproduction of already well-known facts and theories. The point of departure in this paper is rather what students actually have the possibility to learn. What we learn must be understood as an aspect of the activities we engage in. In this article the formation of students in the school science laboratory is analyzed within a cultural historical tradition. The research approach is ethnographic. Two science classes, grade six and seven, were studied in a Swedish midsized compulsory school during one school-year. A conclusion is that both students' laboratory skills and their abilities to discern, classify, and represent nature and the physical reality is developed.

Background

> Science teaching must take place in a laboratory, about that at least there is no controversy. (Solomon, 1980, p. 13).

School science may appear to be firmly embedded in the school laboratory. Even if laboratory work may not be a practical reality in all parts of the world it has been considered worth striving for all over (Jenkins, 1999). The praise of hands-on practical work in a school laboratory has been part of the rhetoric of science education for over a hundred years. In 1954 Paul Hurd examined articles on science education published in the journals *School Science and Mathematics* and *Science Education* between 1901 and 1951 and he concluded that:

> Consistently throughout the fifty-year period of the study science teachers have rated individual student laboratory experiments as the prime essential for a good science course. (a.a. p. 94).

During the 1960ies and 1970ies laboratory work became an established way of organizing science education in Western Europe and North America and a similar development followed in the developing countries in the 1970ies and 1980ies (Ntombela, 1999). In Great Britain school laboratory practice was established during the late 19th century primarily in private schools and grammar schools combined with an ambition to teach scientific methods (Jenkins, 1999). Also in Sweden, following developments in Great Britain and Germany, student laboratory work was introduced in grammar school Physics and Chemistry in the late 19th century (Kaiserfeld, 1999).

In Sweden today, however, we can observe opposite tendencies where practical work is excluded from everyday-work in science classrooms. Following the growth of independent schools in Sweden, is a less expensive science education without school laboratories (cf. Ståhle, 2006). This raise questions if, and in what ways, the abandonment of practical work matters for *what* students will be given possibilities to learn in school science.

Learning possibilities in the school science laboratory

School laboratory practices have involved a range of different tasks from tasks where data is gathered to verify a principle to inductive tasks where data is gathered to formulate a principle (Lunetta, 1998). Also forms of instructions have varied from highly structured to open inquiry (a.a.). We can also distinguish between content-related (or rather concept-oriented) and procedural tasks (Halldén, 1982, p. 98).

There are different arguments for practical work in school science. The first argument is that practical work would be more efficient in promoting learning than other ways of teaching. This is what Swedish teachers value the most in practical work. Högström, Ottander & Benckert (2006) show that teachers find cognitive aspects such as understanding of scientific concepts, reflection on practical work and linking science to everyday-life to be the most important aims of practical work in lower secondary science education. The second argument is that some educational content could only be taught through practical work. The third argument is that it would an end in itself for science education to copy the ways of working in science. Both the first and the second argument have been seriously challenged by research and the third appears to be more of a value-statement, it could be a valid argument depending on the aims of science education.

Derek Hodson (1996) identifies three kinds of learning potentially possible through scientific inquiry. These can be related to the first and second arguments above concerning for practical work as an efficient way of learning and that some educational content can only be taught through practical work. The learning prossibilities Hodson identifies are: *First*, conceptual understanding of what is being investigated. *Second*, enhanced procedural knowledge e.g. learning more about experiments and correlational studies and acquiring a more sophisticated understanding of observation, experiment and theory. *Third,* enhanced investigative expertise which may develop into scientific connoisseurship.

Several studies have questioned the learning made possible in practical work (cf. Psillos & Niedderer Eds., 2002). Empirical research show that students do not engage in an activity of producing knowledge based on observation (Bergqvist & Säljö, 1995; Millar, 1998; Wickman & Östman, 2002). Instead students tend to reproduce already known facts and theories (Beach, 1999; Fairbrother & Hackling, 1997; Nott & Wellington, 1997). One explanation is that students lack necessary theoretical lenses for understanding the experimental set-up and interpreting something as scientifically interesting data (Bergqvist & Säljö, 1995). Students also do not engage in scientific writing – writing laboratory reports rather seem to follow a recipe-like formula (e.g. Andrée, 2007 p. 89; Knain, 2005). cc (cf. also Roth, 2003). Robin Millar (1998) even concludes that parallels with the activity of 'real scientists' are misleading and unhelpful and he calls for a clearer understanding of practical work. Millar (1998) argues that practical work "…has to be understood, and judged, as a communication strategy, as a means for augmenting what can be achieved by word, picture and gesture" (p. 30). A troublesome fact, however, is that phenomena are difficult to reproduce reliably; therefore practical work may not provide the desired support for accepted scientific accounts of phenomena.

Using the learning possibilities identified by Hodson (1996) we can, based on previous research, say that: *First*, practical work in the school science laboratory might help students develop conceptual understanding of what is being investigated (but it is not self-evident that this will be the case). *Second*, concerning enhanced procedural knowledge it is not probable that students learn very much about the nature of observation, experiment and theory just by doing practical work. Much research point to that fact that there is little resemblance to 'real' scientific inquiries but also based on that fact that students do not learn about aspects of nature of science without explicit instruction (Schwartz, Lederman & Crawford, 2004). *Third*, the question of enhanced investigative expertise is a more open-ended question even though questions can be raised based on the claims of little resemblance between science educational practices and science practices.

A conclusion is that there is not much research that supports an idea of practical work as an *essential* part of science education. The aim of this article is therefore to study the formation of students' investigative expertise in the school science laboratory in order to contribute to a clearer understanding of potential merits of practical work.

Formation of students' investigative expertise in school science laboratory practice

Here I will develop two aspects of investigative expertise that is focused in this paper. First investigative expertise includes students' appropriation of new ways of acting with cultural resources of the school science laboratory. Second, investigative expertise includes ways of seeing and experiencing phenomena investigated through practical work.

To know something is to be able to participate in particular ways in particular cultural-historical practices (cf. Andrée, 2007; Leontiev, 1977/1986; Roth et al, 2005; Szybek, 2005). This is a valid statement also for educational practices. As we engage in activity, in as well as outside of educational practices, we develop relations to the objective and social world and appropriate particular ways of acting with cultural resources (both physical and intellectual tools). Through work, our ways of reasoning, experiencing, discerning and interpreting the world is developed.

Through students' participation in practical work in the school science laboratory enculturation into a community of science might be constituted insofar students appropriate new ways of acting with resources, new ways of relating to social objects, new ways of seeing and experiencing the world. Enculturation is a dialectical concept that refers to a person's concurrent production and reproduction of culture through activity. Enculturation involves the appropriation of socially established ways of acting with cultural resources, learning to discern different aspects of the world and the development of social relations with the surrounding world.

Our bodily experiences are not objective but changed through our participation in cultural-historical practices (Luria 1976, p. 20f). Through enculturation the body is formed differently in different practices. One example is sociologist Karen Knorr Cetina (1999, p. 94) description of the emphasis put on bodily experience, and the ability to use the body as a tool, in molecular biology laboratory practices compared to the high-energy-physics laboratory practice at CERN. The importance of the researcher's body is expressed through a culture of emphasizing laboratory skill and first-hand laboratory experiences. In particular enculturation into epistemic cultures involves the appropriation of strategies for the production of knowledge with available resources and norms for cooperation with other participants (cf Knorr Cetina, 1999). Learning to discern aspects of a phenomenon is at the same time bodily and intellectual (cf. Goodwin, 2003). Through enculturation our consciousness, our relations and our abilities to participate in different practices change.

School science laboratory is a particular kind of epistemic practice (cf. Claxton, 1991; Delamont, Beynon & Atkinson, 1989) with particular tools, ways of reasoning, and ways of relating to the world. In school science laboratory practice students will have the possibilities of appropriating ways of acting with resources of the school laboratory. Intellectual and physical resources might involve concepts, algorithms, manoevers, procedures and physical artifacts (cf. Wertsch, 1998). Through interaction with the physical reality one can devlop skill, a practical knowledge, at handeling the resources (Rolf, 1995, p. 116). The appropriation of ways of acting with cultural resources of the school science laboratory can also be talked about in terms of development of laboratory skill.

The questions pusrued in this paper concerns the investigative expertise that students might delevop through participation in practical work in a school science laboratory. The investigated expertise is operationalized as development of laboratory skill and abilities to discern phenomena in the surrounding world.

Methods and Samples

The research approach is ethnographic. Two science classes, grades six and seven, in a Swedish midsized compulsory school were studied during one school-year. Both classes were taught by the same science teacher.

In Physics and Chemistry students do practical work in the school laboratory once a week in groups of girls and boys only (i.e. approximately half the classes participate in lessons in the school science laboratory). In Biology, however, students did not have any practical work in the school laboratory. The total number of lessons including practical work in the school science laboratory is twenty-one. Two of these are teacher-led practical demonstrations. Nineteen include students working on practical tasks.

During fieldwork a variety of data was collected by me through participant observation. Data include field notes, audiotape recordings, teaching materials, and some student work. The data analyzed in this article include all practical work. Refences to data are denoted “T” for transcription, “F” for filed notes, name of textbook or other material cited. Also date for the event is noted e.g. “2003-05-28” and what group of students involved e.g. “G6 girls” (grade 6 the group of girls).

Results

The results shows that the bodily formation made possible in laboratory work involve the development of abilities to act with physical tools of the school science laboratory and the development of abilities to discern aspects of the physical reality.

Developing laboratory skill

In the school science laboratory skill involves abilities to master laboratory tools in ways that appear suitable. Students develop laboratory skill as they come to master laboratory equipment and relate different pieces of equipment to one another. Students learn to master certain artifacts as tools for measurements, filtration, heating.[1]

In the studied school science laboratory students develop skill through the modeling of procedures of peers and their teacher. The teacher introduces students to laboratory work through modeling how the tools of the school laboratory are dealt with: “Do as I show you”. All practical work begins with the teacher showing in lesser or greater detail how the laboratory task is to be performed. Sometimes the teacher shows students how to perform the task in full. When students are neutralizing acid the teacher first neutralizes acid in a beaker at the front desk and shows the students how hard it is to get the desired color change. The teacher makes several attempts before she manages to get ‘the right green’ i.e. a neutral solution. Even if the teacher does not always model complete tasks, there is always some procedure that is modeled. It could be techniques for measuring water in a cup, weighing a powder, or how to moist indicator paper with a glass stick. By bodily visualization the teacher relates the artifacts of the school to one antother. The demonstrations are regulating, as the teacher creates a norm, or a standard, for students practical work (cf. Rolf, 1995, p.107f).

[1] In Chemistry and Physics, some differences concerning the resources used can be noted. In Chemistry, students learn to master the Bunsen burner, particular laboratory techniques (in particular the setting up of a filtration). In Physics, students are introduced to artifacts related to particular conceptual systems e.g. the dynamometer, oscilloscope etc.

Learning to measure

In most of the analyzed practical tasks there was something to be measured (9 out of 12 tasks). It could be volume, mass, weight, pH, current, resistance or voltage.

In the school laboratory *particular procedures for measuring* apply. In practical tasks where students are to measure something the teacher starts the lesson by showing students how to measure. When students in grade 6 are to measure 2 grams of potassium nitrate, the teacher begins demonstrating that students should put a filterpaper on a scale, reset the scale and then finally use a spoon to put the potassium nitrate on the scale (F 2002-10-23, G6boys/girls).

Students acquire a *particular kind of precision* where different measurement precision is valid in different situations. E.g. the instructions to measure 50 milliliters in a beaker and 50 milliliters in a graduated cylinder imply different precision. In a practical task on Archimedes' principle water is to be measured in a graduated cylinder, whereas in the task of distilling caramel colored water, water is to be measured in a beaker:

> Teacher: And what are you supposed to do then? Joakim.
> Joakim: "Add one hundred milliliter water in a beaker, add"-
> Teacher: That's enough. It's not more exact than pouring to the one-hundred-milliliter-mark on the beaker (*points at the mark on the beaker)* (F 2002-11-20, G6 boys)

For this distillation task the precision is approximate. The teacher demonstrates with her hand the amount of water needed. As students participate in a laboratory practice where both beakers and graduated cylinders are used for measuring volume, possibilities are created for students learning to discern the different types of precision required in different situations.

During another lesson Anton asks how much "two spoons" are. That he asks this question can be understood as an expression for that he has appropriated the rule that different measurement involve different precision, in other words, that how much a spoon is, is context-bound:

> Teacher: No. First you have this here, then you pour in the carbon. Here, carbon powder. Two spoons.
> Anton: How much are two spoons?
> Filip: Two spoons.
> Teacher: One spoon, it doesn't need to be a giant measure [jätteråge]. But like that. Two spoons.
> Anton: So it's sort of not so important how much it is?
> Teacher: No, the amount is not super important. (T 2002-11-13, G 6 boys).

The teacher answers Anton that it doesn't need to be "a giant measure" and that the amount is not super important. The meaning of two spoons could be different in different situations depending on the practical task. Anton's question is an expression of him having acquired the norms of measurement precsion in relation to different measurement tools. Filip's quick reply that the two spoons are two spoons is similarly an expression of him not having appropriated the measurement norms in the school science laboratory. He does not recognize the question 'how much two spoons are' as a question to be asked. When the teacher acknowledges this a relevant question the norm of measures being context-bound becomes explicit. This conversation thus involves possibilities for students' learning.

In the practical task on Archimedes' principle the teacher underscores that students should only record one decimal when reading the dynamometers; the calculations will be too complicated otherwise.

> Teacher: Eh, just use *one* decimal in your numbers. Don't try to estimate to zero point seventy-five but decide that its zero point seven or zero point eight. Otherwise there'll be too many numbers to calculate with (T 2002-10-22, G7 girls)

The students are *not* to do as precise readings as possible; rather precision is related to how the numbers are to be used. As in the tasks involving measuring weight and volume it is a question of resonable precision.

While working on the task on Archimedes' principle Hannah and Petra discuss with which precision they are to measure the weight of the cylinder that they have put in a water-filled graduated cylinder.

> Petra: You are to measure how much it weighs first.
> Hannah: Yes. It weighs… two point… ah let's say that it's two Newton.
> Petra: Okay.
> Hannah: It weigh-
> Petra: Two point one. Two point one.
> Hannah: No, it's got some water on it also.
> Petra: But-
> Hannah: Two Newton. Because ”that will be for the best”.
> Petra: The cylinders weight in air. (T 2002-10-22, G7 girls).

Hannah says that it will be for the best if they write that the weight of the cylinder is two Newton rather than two point one. Hannah is suggesting a significance of one number instead of two. When Petra does not accept her argument that "it's got some water on it" as ground for adjusting the reading Hannah just says "that will be for the best". Petra does not argue and they then continue with their next measurement. Hannah uses the dynamometer to measure weight in relation to the precision reasonable in relation to the purpose of the practical task (i.e. to show that the buoyant force of the surrounding liquid is the same as the weight of the displaced fluid) and in relation to the constraints of the measuring procedure (that the water on the cylinder does matter for measurement accuracy). We could say that Hannah has appropriated the norms of the school science laboratory for how to act with measuring tools; she displays measurement skill.

Learning to fold a filter paper

Filtration is a technique for separating different substances. Being able to perform a filtration including folding a filter paper appears to be an important sign of laboratory skill in school science laboratory practice. Students are frequently required to do this.

One afternoon in the staff cafeteria one of the science teachers, Ted, tells us about the student teacher he is currently supervising:

> Ted says that he needs to go to his student teacher. The student teacher had asked him how to set up a filtration, how to fold a filter paper and why it's supposed to be moistened. He remarks somewhat ironically that she's not supposed to be out teaching yet, she wont be a qualified teacher until after Christmas. Ted ends the conversation by saying that he's not so fond of the new teacher training programme. (F 2002-10-14, informal conversation in the staff cafeteria).

The student teacher did not know how to fold a filter paper correctly (that it is supposed to be folded on the middle twice, put in a funnel and then moistened). The conversation with Ted highlights the importance of being able to perform a filtration; it is held as an important part of a science teacher's content knowledge. As previously described in this paper, much teacher work in relation to practical work involves *modeling the trade of the school science laboratory.*

Folding filter papers is a common student difficulty. Many students express that it is hard, they do not remember how to fold, or the paper tears as they try to fold it. Sometimes it just goes wrong and the liquid supposed to be filtrated runs right through:

> Lukas fetches a filter paper that he puts on top of the funnel. Then he presses it down with his index finger.
> Naoki: You're supposed to fold it.
> Lukas folds it first on the middle and then once more on the middle.
> Naoki: Lukas you forgot something. You're supposed to moisten it.
> Lukas unfolds the paper and goes to the tap to moisten it. When he tries to fold it, it won't work. Instead Naoki comes and folds it. He too, fails and Lukas throws the paper away. Then their third group member Jarek fetches a new filter paper and tries to show Naoki and Lukas how they are supposed to fold it. But Jarek doesn't quite get it right either. Naoki now folds a dry filter paper, Lukas moisten it and puts it in the funnel.
> Lukas: But shit, it's torn.
> Jarek: It doesn't matter (F 2003-02-11 G7 boys).

In the field notes above students try to help each other with the folding of filter papers. In other situations the teacher is called upon to fold the filter paper. Also, students that have acquired the skill of folding filter papers, are frequently asked for help by other students. Being able to fold a filter paper appears to be a distinguishing ability in the school science laboratory.

Learning to master the Bunsen burner

One frequently used artefact is the Bunsen Burner. Delamont, Benyon & Atkinsons (1988) writes about the Bunsen burner as the foundation for school science in Great Britain. The Bunsen burner is used in *all* the practical tasks I observed in Chemistry but not in any of the Physics tasks. In the studied school science laboratory the Bunsen burner might be viewed as foundational to Chemistry education but not to general science education.

The teacher introduces the Bunsen burner to students in grade 6 during their first practical lesson in Chemistry. She puts it on the front desk, ignites it and shows students what will happen as she opens and closes air supply. The six-graders express great interest. They ask questions and comment on the look of the flame. (F 2002-10-23 G6 boys). The introduction of the Bunsen burner is marked with students' taking a "Bunsen burner license". On the license one can read that the student has passed a test and displayed knowledge on how to ignite the burner, how to put it out and how to deal with issues of safety. The license also states that the student from now on has the permission to use Bunsen burners in the school laboratory. The "Bunsen burner license" underscores that the Bunsen burner demands particular knowledge and safety precautions. The science teacher gives or denies admission to working in the school science laboratory when issuing licenses. It can be regarded as a *rite de passage* where students are given a new status as science students.

In order to be able to run the Bunsen burner students need to know how to master the burner in itself but also to mount the other equipment needed. Students identify the different physical objects of the school science laboratory as different laboratory equipment with different names and uses. E.g. the Bunsen burner is a thing identified as something that contains gas and can be used for heating substances. Relations are established between the Bunsen burner and other laboratory equipment such as tripod and beaker. There is a finite number of socially evolved modes of relating the Bunsen burner to the tripod i.e. to place the beaker on the tripod over the Bunsen burner. Students judge what a good flame for a specific task is.

The Bunsen burner is used in the investigation of and processing of substances. When using the Bunsen burner to solve zinc in hydrochloric acid three girls engage in a discussion on what is a good flame: Is it too small or too strong? Is the acid boiling too vigorously or not? In the excerpt below the girls formulate criteria for determining if the flame is appropriate:

> Helena: It's boiling. I have to turn this down.
> Jessica: No, it won't work, it'll go out. It's already on the lowest. Look if it's too low then=
> Helena: It's boiling like hell. Get it up!
> Jessica: See, there's almost no flame.

In the above excerpt the girls discuss whether or not the flame is too small or too large and is the acid is boiling too vigorously or not, in order to determine what flame is appropriate for the task. The criteria used are: (1) the range of the Bunsen burner, (2) the behavior of the hydrochloric acid, and implicitly (3) the size of the flame based on previous experience.

The Bunsen burner is circumscribed by fears for making dangerous mistakes. In the beginning of the referred laboratory work above Lisa, Jessica and Helena discusses who of them that dares to ignite the Bunsen burner:

> Jessica: No, but I don't want to, I don't want to.
> Helena: No, but come on. Oh, you're chicken [chicken is said in English]
> Teacher: What's the problem girls?

> Jessica: I don't dare to do this, I just dare to turn it on and then she says that I'm chicken, she who doesn't dare to do any of it.
> Teacher: Try now Jessica.
> Jessica: I don't dare to. I don't want to get my hand burned off [avbrunnen]
> *((The teacher takes the matches and ignites the burner.))*
> Jessica: See. I would have been scared to death [skiträdd.]
> Helena:"Super maan" [said in English]. (T 2003-02-11, G7 girls).

In order to master the Bunsen burner, students don't just need to know how to adjust the flame but also to dare to approach it.

In the school science laboratory students will be given the possibility to develop laboratory skill including mastering particular ways of measuring, and physical tools such as the Bunsen burner and filtering-equipment. Students also work with techniques for measuring related to different subject matter areas, e.g. measuring pH, weight, voltage etc. The lived curriculum (cf. Andrée, 2007) thus involves particular techniques and methods.

Learning to discern sensations in laboratory work

Students develop a particular kind of perception through practical work. Abilities to smell, see, taste, and hear is formed. When working in the laboratory particular techniques for sensing is to be deployed. Students also learn to discern, name and categorize sensations and to create representations of bodily sensations. In this work, the teacher can be described as a participating semiotician structuring and labelling different sensations (cf. van Oers, 2001). The formation of students' sensational abilities is a particular form of bodily enculturation that is simultaneously intellectual (cf. Goodwin, 1994; 1997; 2003).

In several practical tasks students use smell, vision, taste and hearing as tools for discerning critical aspects of laboratory work. Taste and smell is used to separate between different substances. To see or hear something *as* something is not trivial. Vision is used to identify states e.g. chemical states (a liquid is boiling or neutral). Hearing is used to create representations of sound. In some incidents students' sensory formation is made explicit e.g. when students neutralize hydrochloric acid they come to discuss the question if the colour of the solution was green in the sense of neutral.

Sensory procedures

There are particlar procedures or norms for smelling and tasting in the school science laboratory. Eating and tasting is normally explicitly forbidden. In the Chemistry textbook students can read what they are to observe carefully when doing practical work in Chemistry. The textbook reads:"**Tasting prohibited.** Never taste a substance unless the teacher explicity said that you may." (Bold in original, *Kemi Lpo bok 1*, 1996, p. 2). When students are to taste a liquid in one practical task they are instructed to do it by dipping a finger in the liquid and tasting. Also for smelling particluar techniques are deployed. The Chamistry textbook shows a woman smelling a green soulution in a test tube. The text below deals with the smelling of substances in science education:

> *Before you smell an unknown substance you should take a deep breath to fill your lungs with air. Keep your nose at a distance of some centimeters and fan with the hand above the opening. In this way the fume is mixed with the air so that you will only breath a small dose of the substance.* (Italics in original, *Kemi Lpo bok 1*, 1996, p. 2).

Discerning sensations

In one practical task students filtrate Pepsi. One purpose with the task is for students to learn about filtration as a laboratory technique. One part of the task is to boil Pepsi in active carbon [aktivt kol]. In the excerpt below Anna, Wilma and Matilda discusses whether or not the Pepsi is boiling:

> Anna: How long are you supposed to hold it here? Ann! Ann?
> Wilma: It's supposed to boil.
> Anna: Does it?
> Matilda: Ann has it begun boiling?
> Anna: Has it begun boiling, or?
> Läraren: Is it boiling?
> Anna: I don't know. (F 2002-11-13, G6 girls)

To see if a liquid is boiling is not just an observation of what is happening with the liquid but the seeing involves knowledge of what it means that something is boiling and what signs I am to look for in order to determine if it is boiling or not. Seeing therefore is both linguistic and conceptual (cf. Bergqvist & Säljö, 1994; Goodwin, 1997).

In a laboratory task students are to neutralize hydrochloric acid, colored with the indicator BTB (bromtymolblått), with natriumhydroxid. Jesper and Anand discusses how green the green solution is supposed to be in order to be chategorized as green, i.e. neutral:

> *Jesper adds a drop of NaOH.*
> Anand: It's turning green. It's turning green.
> Jesper: No, it's got to be green.
> *Jesper adds another drop of NaOH. The solution turns blue. Jesper adds a drop of HCl and the solution turns yellow. After some more drops of NaOH and HCl they manage to get a green solution.*
> Anand: Okay, it's green now. Yes that's enough […]
> Jesper: Now it's green I think.
> *The teacher now tells Anand to get a grid in a cupboard in the back of the classroom.*
> Jesper: Ann does this count as green? (F 2002-12-10, G7 boys)

Students try to discern what characterizes a green solution: When is a solution green? How 'green' is a 'green solution' supposed to be? How is a green solution discerned from a solution that is not green?

The teacher confirms that the solution may be classified as green through her instruction to Anand to fetch the equipment needed for the next step of the practical task (i.e. to set up the Bunsen burner to indust the solution).

In other situations we cam imagine a range of green nuances from bluegreen to yellowgreen. But in the neuralization of hydrochloric acid a particular green is to be recognized as a sign of a neutral solution being achieved. In this context, Jespers question of whether the solution can be regarded as green becomes a reasonable question. To discern what green is to be regarded as ‘green’ is something that students can learn to discern through interaction with the teacher and bodily experience of different greens in school science laboratory practice (cf. Goodwin, 1997).

Tasting and smelling are used as methods for separation if different substances. During one practical task the teacher says: If you are to find out what the substance is. If you are to separate salt and sugar it’s good to know how salt and sugar tastes. (F 2002-11-15, G6). In laboratory practice smell is used to separate substances on several occasions. In one practical task students are to investigate how sour ammonium, acetic acid and distilled water are. One group who mixed their test tubes then had to use smell to separate the colorless liquids (F 2002-12-03, G7 girls). During one teacher demonstration where iron and sulfur was heated the teacher discusses with the children how they would be able to know if they produced iron sulfide or iron sulfate:

> Teacher: What will happen? […]
> The teacher writes the chemical reaction on the white board: $Fe + S \quad FeS$.
> Teacher: How can you say this out loud using common words?
> Under the reaction forumla the teacher writes the names iron, sulfur and iron sulfide.
> Teacher: iron sulfide, sulfite smells like
> Filip: Shit [in Swedish skit which rymes with sulfit]. Sulfite smells like shit and sulfate smells like food [in Swedish mat which rhymes with sulfat]. (F 2002-12-11, G6 boys)

In the excerpt the teacher focus students’ attention on the fact that smell may be used to determine that chemical reaction has occured, but also what chemical reaction. Filip reproduces the memory rule ”sulfit luktar skit och sulfat luktar mat” which can be used as a tool in discerning whether the product is sulfit or sulfat. The rule is a tool for the organization of olfactory experiences.

Both discerning whether a new state has been enetered and to seprate different substances are questions of classification of the surrounding world. Formation of the ability to determine if a solution is neutral, if the liquid has the right green color, is a sort of sensory formation in the school science laboratory. We can understand the classifications of sensations as something that is formed in practice through interaction with more experienced participants.

In laboratory tasks questions are asked if and when something happens. This involves discerning change, acknowleding a process or phenomena, and what changes are to be regarded as essential. Lisa, Nora and Dhara have neutralized hyrdo-chloric acid and are boiling the solution. Now, as they stand whatching the beaker with the green solution, they ask the teacher why nothing happens.

> Lisa: Ann, nothing happens.
> Teacher: Yes it has to boil some.
> […]
> Lisa: Nothing happens. Listen (the liquid rattles).
> […]
> Teacher: Here things begin to happen too.
> Lisa: Ann. Something fell down.
> Teacher: It's salt that is [salt is beginning to form in the beaker].
> […]
> Lisa: Hey, that's cool. Look. (about the salt chrystals forming in the beaker) (F 2002-12-10, G7 girls)

To Lisa boiling does not seem to be a sign of change. Even after the teacher points to boiling as the desired change Lisa expresses that she cannot discern any change. Lisa's difficulty to discern that anything is happening is an expression of the difficulty in understanding phenomena that can arise when people lack access to necessary intellecrual tools. To describe results and the desired change is easy for a person whith knowledge of industing as a chemical method (cf Bergqvist & Säljö 1994). The teacher also knows what result to expect from students' practical work which the students themselves do not.

Creating representations of sensations

Writing a laboratory report is a way of creating representations of the practical work done. Sometimes students also work with the creation of other represenations of sensations in words, pictures, and models.

In a practical task on aucustics students are to produce different sounds with tuning forks and then describe the different sound. The task involves three different investigations. The first one i sto start the tuning fork by hitting it against the table and then describe the sound produced in air, when it is put on a table, a wooden box and a plastic box. The second investigation is to take two tuning forks, hit them against the table, put them on the table simultaneously and describe the sound. The third investigation is to take a large tuning fork, hit it against the table and then pass it by the ear. The instruction is to describe the sound. In other words students are to create language representations of the sound they produce with the tuning fork following the particular instructions.

Two girls, Moa and Dhara, hit the tuning fork on the table and then listen to it several times over and over. But what does it sound like? They hit the tuning fork against the table again and then put them against the table one at a time:

> Moa: A whale. It sounded like an angry whale. I wrote that it sounded like an angry whale. Because I think it did. Okay, now we're to write what we did. We hit tuning fork against plastic and wooden boxes. Hit ((*writes*))).
> Dhara: Like a whale? (T 2003-05-06, G7 girls).

The girls write that it sounds like an angry whale in their laboratory reports. They then fetch the wooden and plastic box. Moa hits the one tuning fork hard against the table and puts it on the wooden box:

> Moa: It sounded like a clarinet. Or like a horn of some kind ((*hits again*)). But that there sounds like, that there sounds like some sort of like this ((*hits again*)). I think it sounds lika what's it called-
> Dhara: Some kind of alarm.
> Moa: Okay alarm. We'll write that.
> Dhara: Okay. (T 2003-05-06, G7 girls).

The girls write that it sounds like an alarm when they put the tuning fork against the wooden box. Moa then starts the tuning fork and puts it against the plastic box. She does it several times asking what it sounds like:

> Moa: It sounded lika a screaming baby. What do you think it sounded most like?
> *((Moa hits the xx against the table and puts it against the plastic box.))*
> Dhara: Hm it sounds ”eiehe”--
> *((Moa hits the xx against the table and puts it against the plastic box again.))*
> Moa: It sounded like a buzz. A bumble bee or?
> *((Moa hits the xx against the table and puts it against the plastic box again.))*
> Moa: But like a-
> Dhara: A sigh.
> Moa: It sounded like a sigh. Sigh. ((*Writes*)) ”and-the-fat-tun-ing-fork-sound-ed”. Okay let's start with this one now. (T 2003-05-06, G7 girls).

Dhara fetches the big tuning fork and Moa returns the boxes to the teacher's desk. Dhara hits the big tuning fork against the table and then passes it by her face. She asks Moa what she is supposed to do. Moa says that it was something with the ear. Dhara then asks the teacher, who answers:

> Teacher: Yes, you were supposed to pass it by the ear. Slowly when it sounds and then you're supposed to describe the sound if you recognize it from somewhere else (T 2003-05-06, G7 girls).

When the teacher talks to the different groups of students, she underscores that the students are to recognize the sound in the third investigation. Moa then says that it visslar and then she and Dhara continue writing their reports. As results they write that it sounded like an angry whale, a sigh and an alarm.

Moa and Dhara creates common everyday descriptions of sound with no relation to an aucoustic subject matter content. We can understand their descriptions as them lacking access to relevant science concepts for classifying sound. In the practical task students would hear the same sound as the teacher but they lack the tools for dicerning and creating representations of what they hear. Even if students would notice that the sound is different when the xxx is put against a wooden and a plastic box they do not recognize that this is interesting or that it says something about the properties of sound.

The aucoustic task aim at illustrating some foundational aucoustic principles. But in order to recognize why these sounds are interesting and what aspects of the sounds are interesting you need to know the intellectual tools that acoustics build on (cf Säljö 2000 p. 96). Theacher, on the other hand can, with her access to acoustics concepts, use the xx as a tool for illustrating the properties of sound. The teacher's focus on students being able to recognize the sound fgrom somewhere else refers to a school science tradition where the police car or the ambulace are used as examples of the Doppler effect (which the third part of the task was supposed to illustrate cf. Andrée, 2005). But Moa and Dhara does noy only lack the conceptual resources of acoustics but also the traditions of school science.

Through participation in the school science laboratory students' abilities to discern sensory experince is formed. Students can appropriate ways of discerning, classifying and creating representations of nature and the physical reality with scientific concepts and labels. Through participation in school science practice students sensory abilities are formed and we can speak of an enculturation in a sensory sceintific community concerning ways of discerning, classifying and representing the nature and the physical reality.

Conclusions and Implications

The scope of this paper is to try to look beyond practical work as a communication strategy – what kind of learning do real contact offer? Can it be replaced by words, pictures and gestures? What cannot?

The results of this study shows that even if laboratory tasks are mainly aimed at illustrating scientific concepts, students' laboratory skills and abilities to discern, classify, and represent nature and the physical reality is developed through work in the school laboratory. Even if students do not always appropriate ways of representing sensations through practical work, practical work is a nessary condition for this learning to be possible. Evidently there are aspects of the investigative expertise that would be at least diffucult for students to develop without the experience of practical work. Reading about the folding of filter papers or what green is to be considered green can hardly be taught by words, pictures and gestures. School laboratory practice, thus, cannot be dismissed as a poor communication strategy and not be abandoned without consequences for the educational content of school science.

Almost thirty years ago, Joan Solomon (1980, p. 13) wrote:

> Books of recipes and gardening manuals can be read anywhere, but the smells, taste, labour and atmosphere can only be evoked in those who already know the reality. It is the same with science, and so teaching of it must involve real contact with those aspects of nature which are to be studied.

Solomon's idea is that certain experiences might only be made in 'real contact' with those aspects of nature studied. In so far practical work involve 'real contact' with relevant aspects of nature; practical work could not only be considered a communication strategy. The question left for school administration and policy is whether this kind of student formation is a desired outcome of general science education.

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