Res Sci Educ (2010) 40:505–523
DOI 10.1007/s11165-009-9131-3

Lab Work and Learning in Secondary School Chemistry: The Importance of Teacher and Student Interaction

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Published online: 16 June 2009

Abstract Laboratory work is considered essential in promoting students' learning of science and of scientific inquiry. What the students perceive as important to learn from a regular laboratory exercise is probably affected by the teacher's objectives. We study the extent to which one teacher's objectives are fulfilled during lab work, and how teacher–student and student–student interactions contribute to developing learning experiences from the laboratory exercise. Do students encounter opportunities to learn in agreement with the teacher's objectives? This explanatory single case study includes use of a palette of methods, such as pre- and post-interviews, observations and video documentation from an experienced secondary school teacher and her 8th grade (aged 13–14) students' laboratory work. Our results point to the importance of teacher involvement to help students understand what to look for, how to do it and why. Especially teacher–student interactions during lab work seemed to influence what students perceived as important to learn. In the laboratory exercise in this case, the teacher helped the students to observe and to use their observations in their explanations. The lab work included learning experiences other than those addressed by the teacher, and the teacher's intentions were partially fulfilled. Not only what the teacher says, but also how the teacher acts is important to help students understand what to learn from a laboratory exercise.

Keywords Case study · Interaction · Lab work · Learning opportunities · Secondary school

Introduction

Laboratory work and other forms of practical work in school science have gained a lot of attention over the last decades (Hofstein and Lunetta 2004; Lazarowitz and Tamir 1994;

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Lunetta 1998; Millar et al. 2002). The importance of laboratory work is also pronounced in curriculum statements, science textbooks and teacher education programs, for example. Some even advocate laboratory work as almost the defining characteristic of science education, and it has been seen as essential for developing students' scientific knowledge and their knowledge of science (Hodson 1988; Millar 2004). Furthermore, Hodson (2001) argues that lab work is important for the purpose of doing science, which means: "engaging in and developing expertise in scientific inquiry and problem solving". The purposes and objectives of laboratory work can be characterized in different ways. In research results presented in reviews of school science laboratory work, a shared image of important objectives for students' laboratory experiences appears. Lab work is said to help students learn scientific concepts and to enhance students' interest, motivation, practical skills and problem solving abilities. It is also said to help students develop understandings about science, about scientific work and how science connects to everyday life (Hodson 2001; Hofstein and Lunetta 2004; Johnstone and Al-Shuaili 2001; Lunetta et al. 2007; Millar 2004). In a large-scale survey including six European countries, Welzel et al. (1998) categorized teachers' objectives for lab work in upper secondary schools and at the first-year university level. The teachers' objectives were found to be associated with three important categories: to link theory to practice, to learn experimental skills and to become familiar with the methods of scientific thinking. The teachers considered that the most important objective for lab work was to link theory to practice. In secondary schools, this objective is also frequently addressed (Högström et al. 2006; Johnstone and Al-Shuaili 2001).

Science teaching is a goal-directed activity and the provider of objectives in school contexts is the teacher (Jenkins 2006). Some case studies show that the teacher's objectives play important roles (Hart et al. 2000; Lewis 2002). For example, Hart et al. (2000) showed that students who performed lab work with clear purposes recognized improvement of their scientific knowledge. Furthermore, laboratory work in secondary schools often involves one-lesson laboratory exercises where students have some kind of manual to follow (Hodson 1998; Lunetta 1998). This type of laboratory work is familiar to teachers and students in secondary schools. Case studies in traditional and regular lab work indicate that the laboratory manual and its way of guiding students through lab work influence what students perceive as important (Bécu-Robinault 2002; Högström et al. 2008). Also, the designs of manuals influence which objectives students are able to achieve (Lunetta 1998, Millar et al. 2002).

Lab work in school science contexts gives students access to science knowledge already known and consensually accepted. One illustrative example, familiar to those involved in school science lab work, is that a teacher introduces students to a certain laboratory exercise in order to introduce a scientific concept. In this way, school science laboratory contexts are far apart from real science laboratories (Hodson 1998). For example, the research questions for an experiment in a school science context are provided to students, while in an authentic inquiry the scientist generates the research questions (Chinn and Malhotra 2002). Even if the importance of developing students' knowledge about and skills in scientific inquiry is stressed (Hodson 2001), school science lab work has difficulties in providing such opportunities (Chinn and Malhotra 2002). Gunstone and Champagne (1990) argue that discussions and reflections can make laboratory work successful for promoting conceptual change, more so if small laboratory tasks were used, since more time could be spent on communicating ideas. Jenkins (2006) argues similarly, suggesting that laboratory work in school science laboratory contexts should be seen as acts of communication rather than opportunities for inquiry. Talk and actions are important to make lab work a fruitful learning experience for students (Driver et al. 1994; Duschl and Osborne 2002; Roth 2005, 2006). For example, students and teachers use talk and other forms of communicative aspects, such as body language, during interaction to explore scientific ideas or concepts (Roth 2005, 2006). Such interactions could result in consensus and common understandings of issues brought up during lab work and thereby promote students' learning of science.

Certain difficulties are attached to the use of lab work in secondary schools. Time constraints, lack of money and social issues can be involved when a teacher decides for or against the use of lab work in science classes (White 1996). Many teachers have difficulties in preparing fruitful learning experiences through lab work and the pedagogic value of laboratory work has therefore been questioned, receiving most criticism if lab activities are not well prepared (Hodson 1990; Hofstein and Lunetta 2004; Tobin 1990). In such cases, laboratory activities could become confusing, unproductive and unappreciated. Some studies even conclude that students are mostly concerned with the completion of the laboratory task rather than learning from the laboratory task (Berry et al. 1999; Rop 1998). Knowledge about the complexities involved in the relations between lab work and learning objectives is needed and might help teachers prepare lab work that more clearly provides opportunities for learning.

For secondary school laboratory contexts, Berry et al. (1999) reported that students were "rarely asked to consider the wider purposes of their investigations". Berry et al. (1999) also concluded that students' awareness of both the aim of a specific laboratory activity and its overall purpose were important for making sense of why they were doing the laboratory exercise. However, in regular laboratory exercises in secondary school science, aims and purposes are often not made explicit (Hart et al. 2000). In educational research there are not many classroom studies showing both the teachers' intentions with the activities, the interactions during the activity and also the students' view of the performed lesson.

This study examines one laboratory exercise from regular secondary school science in Sweden. Our purposes are to examine how the teacher's objectives are expressed during lab work, what students perceive as important to learn and how this correlates with activities during lab work. The questions guiding the research are as follows:

1. What objectives for the laboratory exercise does the teacher express?
2. How do teacher–student and student–student interactions contribute to learning experiences for the students?
3. What do the students perceive as important to learn from the lab work?
4. To what extent are the teacher's objectives fulfilled?

Method and Analysis

An explanatory single case study was chosen to study a regular laboratory exercise in a secondary school. A case study such as this offered useful advantages of managing varied empirical material within the case and of making them comparable (Yin 2003). Also, by using a single case design we aimed to illustrate complexities that could be involved in and applied to other laboratory exercises in secondary schools. The case described in this study includes a laboratory exercise in chemistry in a science section about modern materials.

In Swedish secondary schools, teachers are required to adopt curriculum statements as they find them appropriate with regard to the science to be taught. The teachers are free to choose laboratory exercises. This demands higher order teaching skills in order to achieve learning objectives stated in the curriculum for the different science disciplines. For example, the teacher needs to determine what skills are required to help students understand in what contexts certain scientific concepts are appropriate (Gunstone and White 2000).

Initially, the first author observed the whole class of 25 students in 8th grade (aged 13–14) and their teacher (Lisa) during four lessons to gather contextual information. It also afforded the students the opportunity to get to know the researcher and become more informed about the study.

The teacher's objectives were obtained from an audio taped, semi-structured interview prior to the video recorded lesson. This interview informed us about school context, teaching and the teacher's objectives for the selected laboratory exercise. The interview concerned the following questions: Describe a laboratory exercise from your teaching. What are the objectives of that exercise? What do you believe students learn from it? Are these objectives specific or could they be considered general? The objectives were identified using detailed transcript notations of the teacher's expressions. For example, expressions with a strong intonation indicated that the teacher considered a certain statement important (Atkinson and Heritage 1996). Thus, we used details in the teacher's talk to interpret meanings of expressions that could be interpreted as objectives of the specific laboratory exercise (cf. Högström et al. 2006).

The laboratory manual was collected from the teacher at the interview (see appendix 1). What the laboratory manual was supposed to help students to learn or develop was analyzed using a classification model derived from Ottander and Grelsson (2006).

During the video recording of the selected laboratory exercise, 14 out of the 25 students participated. Two digital video cameras (DVC) on tripods were set up in two different positions to ensure that most of the classroom was visible in the video recordings. A remote microphone was also attached to the teacher. A research assistant operated one of the DVCs and the first author operated the other. One DVC was used to track the teacher's activities, such as interactions with student groups, and the other to obtain an overview of activities among the participating students and the teacher. Observations from students' lab work were collected in a content log by the first author to complement data from the video recordings. The video recording, content logging and DVC set-up were inspired by methods from interaction analysis (Jordan and Henderson 1995; Plowman 1998). The analysis of the video recordings included identifying how student and teacher–student interactions were structured, and interpreting what made participants interact the way they did. What appeared to be of importance we described as issues (cf. Stake 1995). For example, teacher–student interaction could be initiated by a question from the teacher or the students about something concerning the laboratory task. This could lead to short or long discussions between the teacher and the students. In such interactions we identified what concerned the participants, thus identifying the issue. If the same issue emerged in interaction with several student groups and if it recurred throughout the lab work, it was considered an important issue. A less important issue did not emerge often, i.e. no more than once or twice during the whole laboratory exercise.

The first author also completed and audio taped post-lab work interviews with all participating students directly after they had performed their lab work. Two primary questions were embedded in semi-structured group interviews (n=7). These were: 'What do you think *the teacher* considered most important for you to learn from the laboratory exercise?' and 'What do *you* think was the most important thing to learn?' The similarity between the two interview questions was considered not to cause any conflict since they had different foci. Rather, by asking the students to state their opinion about the teachers' objectives, we wanted to help them verbalize their own opinions (Kvale 1996). The interview responses were managed as group responses, meaning that for each group we did not specify who actually said what. To clarify the initial interpretation of student group interview responses, we compared our conclusions with analyses of video recordings. This included interpretation of how the interview responses correlated with the ways in which issues emerged in interaction during lab work.

A follow-up interview was performed with the teacher where video recordings from the lesson were viewed. The teacher was encouraged to comment on any part of the video recordings and to reflect on for example how the lesson was introduced. The teacher's objectives (identified in the pre-interview) were also brought up and discussed in relation to activities that could be viewed in the video recordings. This post-interview methodology was derived from stimulated recall presented in Calderhead (1981) and Haglund (2003). In the analysis of the follow-up interview, we identified whether and how the teacher commented on different types of activities, for example if the teacher expressed why she intervened in students' group work. The teacher's comments on and descriptions of for example lab work procedures, objectives and previously unnoticed details were also used in attempts to support interpretations from video recordings.

Results

The findings from data gathered with several different methods as described above are outlined as follows: We describe the settings of the specific laboratory exercise, including the manual. We describe what objectives the teacher expressed. We describe the teacher–student and student–student interactions, the teacher's reflections from the lab work, and analyze what emerges as important in interactions during lab work. We describe student group post-lab interview responses and present what students found important to learn. Finally, we interpret what learning experiences were possible from the laboratory exercise and summarize to what extent the teacher's objectives were fulfilled.

The School and the Laboratory Work Context

The urban secondary school from northern Sweden involved in this study had approximately 400 students from ages 13 to16. This school was fairly typical and it represented several parallels of each grade (seven to nine). All science disciplines (biology, chemistry and physics) were taught separately. The students were taught chemistry, physics and biology alternately during their school year, 2–3 lessons, i.e. approximately 160 min of science every week. The teacher, Lisa, worked as one of the science teachers in the school and she had 25 years of teaching experience. She taught biology and chemistry topics such as organic chemistry for periods of 10 to 12 weeks. The 8th grade students (aged 13–14) included in this case performed laboratory work once a week on a regular basis. However, during these lab work lessons the students were divided into two halves, so each student participated in a 60-minute lab work lesson every 2 weeks.

The specific laboratory exercise in this case was part of a science section in chemistry about modern materials. The unit included three laboratory exercises. The materials were: a super adsorbent, polymers of polyvinyl alcohol (PVA) and expanding micro spheres. The teacher introduced, supervised and supported a group of 14 students during the 60-minute lesson that involved PVA. This material was a solid when dry and could only be dissolved in water, which was the main result that could be revealed through examination with different types of solvents (Task A, appendix 1). In the second task the students were to find out in which solvent a solute of PVA formed a precipitate (Task B, appendix 1).

The students' manual clearly described how to perform the laboratory procedures, figures of chemical structural formulas, and the follow-up questions the students were to answer in their report (appendix 1). The identified objectives in the manual were that students should learn the chemical properties of PVA and find relations between solvents and PVA.

The Teacher's Objectives

In the pre-interview, Lisa said: "I want the students to become interested in science and when they leave this school, I would prefer that the students of their own free will read about science in a newspaper". She also said that new or different kinds of materials could make students appreciate and become interested in laboratory work. Lisa wanted the students to think before they started working with their task and the students' thinking to be involved throughout their lab work. She wanted her students to write down hypotheses, to reconsider if the observed results were reasonable or not and to draw conclusions from the observed results. For example in what way observed results could also be found in everyday life. The teacher's statements indicated a quite well formulated philosophy for teaching lab work.

For this special laboratory exercise about PVA, the teacher's main objective was to work with the concept of solubility to learn the rule of thumb "like dissolves like". Also, she wanted the students to learn about PVA and the organic chemistry that explained its properties (cf. appendix 1), to challenge the students to think about their observations and to make them search for convincing results. Furthermore, she wanted them to use the manual, complete its questions and to write a report in which they summarized results from observations and drew conclusions. Lisa also wanted the students to have fun and to recognize associations with everyday life, i.e. to stimulate interest and motivation.

In summary the teacher's objectives for this lab exercise was that the students should learn the rule of thumb "like dissolves like" and to learn about the PVA and its chemical properties. These objectives correlated with the objectives identified in the manual. Lisa also stated some general objectives for all her laboratory exercises. She wanted the students to think and reflect, to prepare their lab work with hypotheses, to reconsider if observed results were reasonable and to think about associations to everyday life.

The Laboratory Exercise

Interactions between student groups and the teacher were frequent during the laboratory exercise, but not as frequent as student–student interactions. The teacher's involvement was evident in different ways and student groups were primarily encouraged to solve their task within each group. The analysis of interactions during lab work indicated how the teacher's objectives were presented, and in what way they correlated to the activities.

Interactions with Teacher Involvement

The laboratory exercise started with a 20-minute lecture where the teacher (Lisa) first made clear that a report was significant for the evaluation of students' work and also for their grading. The writing of the report was assigned as homework. Lisa's lecture also included descriptions of chemical facts and concepts, such as the polymer structure of plastics, as well as discussions with students about their knowledge of these concepts. The teacher handed out the manual (appendix 1) and she discussed possible risks regarding the solvents to be used and how the students should behave to prevent accidents. When the students were allowed to begin, in pairs appointed by the teacher, they had to gather certain materials and equipment among available items. PVA was provided as pieces of transparent and red dyed foil as well as powder. Lisa made sure that the student groups were ready to proceed with the examination of PVA by briefly addressing for example what kind of beaker to use or what amount of solvent to gather. Some student groups showed confidence in making these preparations, by using the manual to find out what they needed. However, most student groups also checked with Lisa if they had got it right.

In this laboratory exercise the use of the manual appeared to be central, since the use of it was repeatedly evident in several different ways throughout the entire laboratory exercise. The manual was read from during the teacher's introduction, it was part of teacher interaction with almost all student groups and the students' own questions during lab work were often related to it. Furthermore, there were questions written in the manual that were also talked about.

In interactions between students and the teacher three main issues emerged. The issue of safety and risks emerged in four groups, the issue of procedures and equipment in four groups, and the issue of chemical concepts in three groups. These three issues were the most important and how they emerged is described in more detail below. Interaction between the teacher and her students could many times reveal two or more issues. For example, participants' interaction could first reveal that one issue emerged and during their interaction a shift towards another issue could be noted.

The following excerpt of teacher–student interaction illustrates how the issue of safety and risks could emerge. It took place when two students (Jill and Sue, group 5) collected windshield wiper fluid and denatured ethanol from bottles on the teacher's desk into their test tubes.

Lisa: Did you use the same funnel for both [solvents]?

Sue: Yes.

Lisa: How good was that?

Jill: Bad. ((With a grin on her face))

Lisa: 'Cause then you have a mix in the funnel.

Sue: Is that a problem?

Lisa: No, it still works in this case ((smiles)). But if you put it like this—if it had been the wrong substances it could have been dangerous. That's why you make it a habit never to use the same [funnel] for several [substances].

Sue: All right, then we have to do like this. We put the equipment in sequence ((begins lining up the equipment)).

Lisa intervened in these students' way of handling the solvents by asking first how they used the laboratory equipment. Then she explained why she intervened and that students should learn to use appropriate procedures to avoid risks. Hence, to learn a safe way of handling materials that could be necessary if more hazardous material were involved. Besides the example illustrated above, the teacher could also prompt students to bring their material to their working place cautiously or tell them to pay attention to fumes.

The teacher showed a way of behaving that encouraged students to take responsibility and to make their own decisions. Almost all groups that asked the teacher about how to do or what to write were advised to make appropriate decisions. The students asked many questions but longer discussions were rare. Instead, the students quite easily adopted information regarding the issue of procedures and equipment in further lab work actions. For example:

Jonas: Are you supposed to do the same stuff with that one later?
Lisa: It says in your manual what comparisons you can make.
Jonas: OK

And in another group:

Lisa: Now you will make a solution of PVA. That is, you put water in a beaker and then you will get some PVA-powder from me. ((Starts to leave the group))
Pam: This is the water, is it supposed to be cold, hot or something in between?
Lisa: What do you think is better, if you want it to dissolve fast?
Pam: Hot.

In these two excerpts, the students are focused on some of the laboratory procedures and they are asking for clarification of how to do these. However, in Lisa's answers it can also be noted that she tries to make some connections to chemical concepts.

Teacher–student interaction in the following excerpt illustrates student difficulties in examining the PVA, how participants' interaction defined the problem and how they established further actions. This example also shows how the issue of procedures and equipment first emerged when students initiated interaction and how the issue of chemical concepts emerged in the way the teacher interacted with the student group. Jonas and Oscar are the students in this co-working group (group 3).

Oscar: Hey, are you supposed to dissolve *this* in water? I mean, later, with water. ((When accentuating this, Oscar points to the PVA foil))
Lisa: You are at what part? ((Reaches for the students' laboratory manual))
Oscar: We are at this point, at the red and the transparent. ((He points at the laboratory manual))
Oscar: Nothing has happened.
Jonas: We have done foil and the white one.
Lisa: Mm, the white one? Do you mean the transparent? ((Reaches for a piece of transparent PVA-foil))
Jonas: Mm, that one.
Lisa: Yes?
Jonas: Nothing has happened.
Lisa: Nothing has happened?
Jonas: No.
Lisa: Not in water either?
Jonas: Yes, in hot water it becomes sticky.
Oscar: Yes, it becomes...
Jonas: It becomes like slippery.
Oscar: It kind of melts. ((Both students rub their fingers and talk at the same time))
Jonas: And in cold water it becomes diluted, in strands. It becomes like this, like a liquid. ((He points to the beaker containing water and PVA-foil))
Lisa: Then things must have happened?
Jonas: In ethanol, it becomes like rugged and in windshield wiper fluid and acetone there are no differences. Nothing happened. ((He leans forward to read his notes))
Lisa: ((Nods)) No, maybe there are differences between water and windshield wiper fluid and acetone. ((3-second silent pause)) Water and acetone are not chemically equivalent.
Jonas: No. ((He turns to his friend who is taking notes and looks into the beaker containing water and PVA-foil))

Jonas: Look, in water it anyway becomes... in hot water it anyway becomes slippery. ((He stirs a glass-rod in the beaker and both students look into it))

Jonas: Check this out, it doesn't become like this with anything else. ((He turns to the teacher))

Lisa: ((Nods))

Teacher–student interaction started with a discussion about what the students had done, which originated with Oscar's question: "Hey, are you supposed to dissolve *this* [the PVA-foil] in water?" At first, the discussion is to a large extent about what procedures to use and we interpret this as an example of the issue of procedures and equipment. Then the students discuss their observations with Lisa. Oscar and Jonas thought that their observations showed nothing, implicitly revealing that they had used instructions in the manual but not understood that "like dissolves like". Without saying it in exact words, Lisa related the students' observations to the solubility of PVA in water. That is, not explicitly expressed but implicit in her utterance about the comparison to water, she helped students recognize what kind of result could be expected and in what way their procedures had actually revealed a result. This made both students recognize the (expected) outcome of their investigations. They used overlapping talk and showed excitement when they described their observations with utterances and gestures. Thus, the excerpt shows how the students suddenly realize that the solubility varies for different solvents, i.e. dealing with the issue of chemical concepts. This also clearly shows that the students learn through interaction with the teacher and that the teacher is important for students' understanding of what is relevant in their observations. In fact, the teacher–student interaction is necessary for the students' learning.

The three important issues in teacher–student interactions were safety and risks, procedures and equipment, and chemical concepts. Several other issues also emerged during lab work, but were not as prominent as the three above. For example, Lisa asked one group of students if they had family members that worked in hospital or any other type of personal care facility and another student group asked the teacher to tell them where the PVA originated from and discussed why the PVA could be useful in hospital laundry. These types of interactions show that an issue regarding everyday associations also emerged in the laboratory exercise, although not very often. In some groups the teacher encouraged the students to make their own decisions. For example, the teacher told students to "decide how to do it, but don't forget to report it". That is, when deciding a specific action, students also had to account for it.

Student Group Interactions

Throughout lab work all student groups were actively involved in carrying out their task. If teacher–student interactions seldom developed into longer discussions, this was even more evident in student–student interactions. That is, many students showed each other how they wanted to do different parts of the task instead of talking about them. Students' interactions mostly concerned performance of different laboratory procedures, how to handle solvents in a safe way and how to follow directions in the manual. In fact, one student group did not interact with the teacher at all. This group seemed solely to be following guidance from the manual. When discussions were longer, they mostly concerned what equipment to use and in what way their choices might give successful results.

Our analysis revealed that student–student interactions often included students' use of procedural knowledge, for example how to make solutions. This was mostly visible in interactions that did not include talk. The example of students' use of procedural knowledge including talk that is given below also serves as an example of how the issue of procedures and equipment could emerge.

Glen: ((Picks up one bottle from the teacher's desk)) This one is almost empty. Here we've got—methanol. ((Reads from the contents of the bottle))
Helen: Maybe we should use a funnel when we pour some of it?
Glen: ((Picks up a small funnel))
Helen: Now, we have to pour carefully.

This student group was gathering one of the solvents to use (methanol) and their talk showed that they knew that a funnel might be a useful tool for transporting methanol from the bottle to the test tube. Whether this knowledge is proof of common sense or actually learnt from doing lab work, we could not tell. However, for these students it was important to carefully conduct the procedure illustrated above. The issue of procedures and equipment could also include how to use the PVA-foil and the PVA-powder in different solutions and how to describe observations. Students frequently used their 'know-how' and 'trial-and-error' to complete a procedure. Student–student interactions about what to use also occurred frequently. Students discussed or tried out different equipment such as beakers and pipettes, and different materials such as solvents and PVA-foil.

The presence of possible risks seemed to be of importance to some groups; hence safety and risks also emerged as an important issue in student–student interactions, especially when they were handling the different solvents. One such example where two student groups briefly discussed acetone is illustrated below.

John: You get completely dizzy when you smell that. ((Frowns))
Ted: ((Removes cap from the bottle)) You are supposed to use a drop of this on a [piece of PVA-foil]. ((Looks into the manual))
John: I've never tried smelling this before.
Adam: It isn't smart to do either.
Keith: It doesn't smell that well.

In this example, three of the students (John, Adam and Keith) were expressing associations to acetone that could be related to personal experiences, beliefs and opinions. The intended use of acetone or other possibly hazardous solvents in the laboratory exercise not only made students discuss how to use the solvent as Ted's expression indicated. It also affected their way of putting the use of solvents into a wider, in this example personal, perspective. Hence, student–student interaction indicated that solvents were both chemicals in this particular laboratory exercise and chemicals with properties that students could find important outside the laboratory.

In student–student interaction during laboratory work, we could identify that the issues of procedures and equipment, and safety and risks were most prominent since they emerged in some way in all student groups. Other issues did emerge, for example chemical concepts, but were only briefly addressed by some students. We would also like to point out that most student–student interactions concerned how to perform the task. The students did not play at all, and only briefly a few students talked about stuff that could belong elsewhere such as sports. In student–student interactions we could see that all student groups used the manual not only in the beginning of the task. Additionally, it seemed important for the students to discuss how to write a report.

Teacher Post-interview Comments

The teacher's comments helped us understand what she was thinking when she interacted with the students. Lisa commented on her introductory lecture, student–student interaction and teacher–student interaction when watching the video recordings. She stated that she wanted to perform a thorough introductory lecture to point out the chemical differences between PVA and other plastics: "It *looks like* a plastic, which makes it logical to compare how it [PVA] is chemically structured compared to plastics." Besides comparisons between visual similarities and chemical differences, she also wanted to include aspects of everyday life in order to help students understand why they were doing the task. Lisa said: "Instead of just telling them to examine some weird substance, I wanted to frame the task in their everyday life." Also, Lisa stated that the introductory lecture included mandatory information about safety and risks since flammable and poisonous chemicals were involved.

When watching the video clip that showed the students making experiments on PVA, Lisa said that she wanted student groups to try the different solvents and to come to the one conclusion that could be expected, i.e. that PVA dissolves only in water. However, ways to examine properties of PVA with different solvents were to be decided by the students and could therefore be set up differently. Lisa hoped that the students could make conclusions in connection to the chemical properties of the substances involved: "My focus was to make them think about if it was reasonable that different things *happen* depending on *what* solution they examine." She stated that it was important to encourage students to find out how their observations could be compared to chemical properties. For example, windshield wiper fluid and ethyl alcohol were equivalent solvents, only with different coloring: "We used both windshield wiper fluid and denatured ethanol. It took time before the students realized that it was actually the same type of solvent, ethyl alcohol, which they were examining."

In summary, Lisa's comments to the introductory lecture showed that aspects of everyday life should frame the task. Her comments to student–student and to teacher–student interactions showed that the students were intentionally encouraged to *discover* the rule of thumb "like dissolves like". Furthermore, her comments also showed that it was obvious that aspects of safety and risks should be included in the laboratory exercise.

What Do the Students Perceive as Important to Learn?

In the post-lab work interviews with the student groups we could identify what students perceived as important to learn. The students' responses were derived from interviews performed directly after the laboratory exercise with each co-working group (n=7). In the interview, the students were asked 'What do you think *the teacher* considered most important to learn from the laboratory exercise?' and 'What do *you* think was the most important thing to learn?' The students' answers to the two questions agreed to a large extent. In student group responses about things important to learn, different aspects emerged as follows.

Six of seven student groups stated that it was most important to learn to perform lab work in a safe way, to prevent and be aware of risks and to know what chemicals were hazardous. Students in group 1 said: "Flammable substances and acetone are dangerous and... you have to take it easy. You have to know what you are dealing with before you begin." Another student said: "I suppose that it was to avoid getting stuff in the eyes, 'cause I don't want to become blind. That wouldn't be enjoyable." (Group 6) The results indicate that the presence of hazardous materials during lab work not only influenced the students' answers concerning what they perceived as important, but also indicating that the use of these materials had an affective meaning for some students.

Furthermore, chemical concepts were considered important to learn in three student groups. Regarding the importance of learning chemical concepts, students could for example state that it was important to learn what differences there were between diverse plastics, or relating to chemical processes: “I guess it was to think about how it reacted with the different substances, the plastic I mean. Or actually, why it reacted as it did.” (Group 7)

Three groups thought that associations to everyday life were important. Such associations included student statements that considered how their laboratory experiences could be relevant outside the laboratory. Students described ways in which the PVA-foil could be used, for example to avoid contact with dirty laundry in hospitals.

Two groups stressed the opportunity to be responsible and to make decisions concerning their lab work. One student said: “I think it was important for us to take responsibility... I think she wanted us to do the lab work on our own, to figure out by ourselves.” (Group 3) The students did not only want to follow the manual or directions from the teacher without first reconsidering the advice they had been given. How to carry out the task was a student responsibility.

Also, one of the groups stated that they enjoyed the laboratory exercise and another group criticized the point of doing the exercise. These opinions were not considered to respond to either of the two interview questions. However, it showed that this class included students who either appreciated the laboratory exercise or questioned learning from it. It also indicated that students did not feel uneasy about expressing their opinions during the post-lab work interview. Furthermore, none of the student groups mentioned laboratory procedures or the equipment used, which indicates that these were seen as obvious aspects of lab work—not something that was also important to learn.

In summary most of the students said that it was important to learn about safety and risks from this laboratory exercise. The students also expressed other aspects; chemical concepts, associations to everyday life, responsibility and decision-making. The teacher’s introduction, the manual and the interactions during lab work seemed to have influenced the students’ opinions about the importance of safety and risks.

Learning Experiences for the Students

During the lesson, Lisa tried to make the students figure out how the rule of thumb was involved in their lab work. The previously presented example of teacher–student interaction with Lisa (the teacher), Jonas and Oscar showed that the teacher and the students discussed how to explain their observations and that the students thereby realized, at least regarding the examined piece of PVA-foil, that solubility differs among different solvents. This showed that students were given opportunities to learn from their laboratory exercise results, and in particular when they tried to explain their observations. Our findings show that teacher–student interactions are important to give students opportunities to develop scientific knowledge.

The teacher’s general intentions included that she wanted the students “to find out by themselves”, and her limited interventions in student group work showed how she acted consistently towards this intention. If student groups were about to figure out how to perform or were only hesitant to perform further actions, the teacher encouraged them to make their own decisions. If they were on the wrong track, she instructed them by guiding them in the right direction. This teaching strategy, to help students make decisions, seemed to have helped stimulate students’ confidence in doing lab work.

There was a great deal of talk and actions regarding awareness of safety and risks during lab work. Many students were obviously affected and perhaps extra cautious while gathering and using the solvents. The students did not want to perform hazardous actions during lab work. When students were asked what was important to learn from the laboratory task, they paid much attention to safety and risks. From all but one student-group interview, we can conclude that the student groups considered it important to learn about safe handling and possible risks. Thus, analysis of interactions in the laboratory exercise revealed that the lab work also included learning experiences other than those mentioned by the teacher in advance.

Students' attention to laboratory procedures and discussions about equipment were identified in their interaction. Student–student interaction largely dealt with procedures and equipment and the students mostly seemed to be confident in performing these laboratory procedures. If there were difficulties with any task, students discussed what to do next or what material to use. In the post-interview, the students did not mention it, indicating that laboratory procedures and equipment was something they did not consider especially important to learn. Neither did the teacher talk about "learning laboratory procedures" as an important objective in this exercise. However, the students were encouraged to use their experiences of lab work.

In this laboratory exercise, the students seemed to have faced opportunities to learn about "like dissolves like", about safety and risks, about procedures and equipment, and to make their own decisions. Our results point to the importance of teacher involvement to develop learning opportunities and to help students understand what to look for, how to do it and why.

To What Extent are the Teacher's Objectives Fulfilled?

The teacher's main objective for this laboratory exercise was to help the students recognize the rule of thumb "like dissolves like". The teacher also wanted the students to prepare their lab work with hypotheses, to learn about PVA, to make their own decisions and to think carefully about what their observations could show. Furthermore, she wanted them to have fun and to recognize associations with everyday life. The teacher's objectives were not expressed explicitly to the students, i.e. neither mentioned in the teacher's introduction nor told in teacher–student interactions.

Our analysis of the interactions and the student interviews showed that at least some of the students seemed to have learned about "like dissolves like". During lab work, this chemical concept was included in teacher–student interactions. It was also evident in every group that the students learned some chemical properties of PVA since they observed and discussed how PVA reacted with different solvents. Most groups figured out that only water could work as a solvent. However, the more complex organic chemistry talked about during the teacher's introduction was not dealt with in interactions during lab work, and neither of the students mentioned any complex organic chemistry in the interviews. Furthermore, three of the student groups mentioned that associations to everyday life were important. This objective was thus at least noticed by many of the students, but from our analysis of the interactions during lab work, the associations to everyday life were not prominent. Also, in this laboratory exercise the students showed interest when they were doing the lab work.

Our findings suggest that the teacher's objectives are partially fulfilled. In addition the lab work included learning experiences other than those expressed as objectives by the teacher beforehand, e.g. the awareness of safety and risks during lab work.

Discussion

The empirical data from this case study reveal the complexity in formulating objectives for a laboratory exercise, to communicate these and to provide learning experiences for the students. Below we discuss the results on the basis of the research questions.

What are the Teacher's Objectives and to What Extent are They Fulfilled?

Our results show that some of the teacher's objectives for this laboratory exercise were fulfilled, even though the teacher expressed none of her objectives explicitly to the students during lab work. Some of the students seemed to learn about the rule of thumb "like dissolves like". The teacher also wanted the students to think and reflect about the lab work and the teacher stimulated the students to do so during the lab work. The teacher wanted the students to make associations to everyday life and at least some of the students mentioned it as important to learn. Hart et al. (2000) argue that specific objectives need to be clearly explained to students. It is possible that such a strategy might have helped the students to reach the intended objectives to a greater extent. However, we conclude that things talked and acted about during lab work to a large extent affected what the students perceived as important to learn and it is probable that such talk and actions during lab work are more important than explicitly expressed objectives. For example, to learn about safety and risks was not expressed as an objective by the teacher, but there was a great deal of talk and actions regarding safety and risks during the laboratory exercise, both in the teacher's introduction and in interactions. Also, almost all student groups stated that it was important to learn about safety and risks in the interviews afterwards.

Neither the teacher nor the students expressed that it was essential to learn about how to perform laboratory procedures. However, the teacher–student and student–student interactions showed that the students were confident with the equipment and the procedures. If the students were uncertain in some way, they got help to proceed by interacting with the teacher. Our interpretations suggest that the students in fact developed their laboratory skills.

About the Learning Experiences for the Students

Student–student interactions often involved how to perform the lab work and how to use the equipment. Also, many groups showed confidence in their actions during lab work. The findings indicated that the students could use their prior experience from doing lab work in these laboratory activities. Our interpretation of student group interactions indicates that they had been trained in reading and following manuals and in presenting their findings in reports. However, the students had difficulties in deciding whether one observation really displayed a result or not. Kanari and Millar (2004) explicitly addressed students' (aged 10–14) reasoning about measurement data and they reported that many students had great difficulty in interpreting data. Results from our study show the importance of teacher–student interactions to help students learn such skills. The teacher can help the students to think about and act in order to improve their laboratory skills.

The findings in our study show that students can learn both chemical concepts and laboratory skills by participating in laboratory exercises. Contrary to Hodson (1990) and White (1996), we argue that lab work contributes to students' learning. Findings in our study show that for the laboratory exercise to be a learning experience, it is important to help students develop observation skills. This is consistent with similar arguments in Hofstein and Lunetta (2004) and Lunetta et al. (2007). When the teacher interacted with the student group that said: "nothing has happened", she made the students focus on what the chemical reaction looked like, i.e. that PVA dissolved in water but not in other solvents. The students seemed to learn how to distinguish chemical properties by using different solvents and in this way approached the teacher's main objective to learn "like dissolves like". We observed that students through interaction with their teacher became aware of what results to account for in their further examinations. Therefore, the results suggest that it is important to help students learn how to distinguish what could be of importance during lab work. Säljö and Bergqvist (1997) showed in a study of a secondary school that students had problems learning from an optics lab (i.e. seeing the light). The students did not get enough help from the teacher to perceive what they were supposed to perceive. There is one major difference between Säljö and Bergqvist's (1997) optics lab and the PVA lab presented in this study. In our case, the students were especially helped to learn to observe and to use their observations in their explanations. The teacher showed awareness of what was important for the students to discern.

We could observe how the students used their procedural skills and that development of these skills in interpreting observations during lab work. On the other hand, we found no evidence that this laboratory exercise encouraged the students to ask their own questions, or that the student–student interactions included other questions than those already given by the teacher and the manual. Chinn and Malhotra (2002) argue that this is one of the important differences between school science lab work and real scientific inquiry, and findings from our case further support this conclusion. We argue that it is not to be expected that students pose research questions, and put forward hypotheses other than guesses, in laboratory exercises that include a manual with a clear procedure to follow. Nor do we believe that it is helpful to include too many aspects in a laboratory exercise for secondary school students. For students to learn about scientific inquiry, we argue that it is better to include lab work that specifically deals with inquiry skills.

What Do the Students Perceive as Important to Learn?

It was evident in the students' responses in the post-lab work interviews that learning chemical concepts was not regarded in every group as important to learn, and laboratory procedures were not mentioned at all. Instead, other issues such as safety and risks were considered more important or more interesting. This issue had no connection to the teacher's objectives as expressed beforehand. Rop (1998) claimed that students rely heavily on what they think the teacher consider important in the laboratory exercise. This is in accordance with results from our student interviews where issues such as safety and risks were considered more important or more interesting than learning of chemical concepts. What the students mentioned as important to learn could in this case partly be explained in students' lab work experience. Repeated inclusion of laboratory exercises in these students' science education seems to develop their skills in performing laboratory procedures and in using equipment. However, these experiences did not make them aware that such skills also can be important to learn.

Our results indicate that especially teacher–student interactions during lab work influence what students perceive as important to learn. That is, not only what the teacher says, but also how the teacher acts, is important to help students understand what to learn from a laboratory exercise.

Conclusions and Implications

It is probably important, as Hart et al. (2000) argue, that objectives for a laboratory exercise should be clearly explained to the students. However, it is not only what the teacher says but also how the teacher acts, that is important for what the students perceive as important to learn. Our conclusion is that the teacher should be clear of her own objectives for a specific laboratory exercise, communicate these to the students and then act accordingly. This is not as easy as it seems since we often have many reasons for our actions and they may not always be apparent to ourselves. It is presumably important for teachers to discuss together the objectives for lab work in general and also the objectives for specific laboratory exercises.

Our study shows that for a laboratory exercise to be a learning experience, it is important to help the students to develop abilities to observe. The students need help from the teacher to perceive what they are supposed to perceive. It is also important that the teacher make evident what an observation or chemical reaction can look like so students account for these observations in their further examinations.

Lab work in schools has been criticized for teaching the students an oversimplified version of scientific inquiry (Chinn and Malhotra 2002). For example the question in a laboratory exercise is often given to the students, while in an authentic inquiry the scientist generates the research questions. For students to learn scientific inquiry it is important that teachers give students opportunities to pose questions, to plan experiments, to learn to observe, to critically discuss results and to make their own decisions. However, we believe that a laboratory exercise for secondary school students should not include too many aspects. Some aspects, like procedural skills and skills to interpret observations, ought to be dealt with often. Other learning experiences for students, e.g. to plan experiments, should be provided in laboratory exercises designed for such purposes.

Appendix 1

Polyvinyl Alcohol[1]

Why is polyvinyl alcohol a different plastic?

Task A.

Your task is to examine properties of polyvinyl alcohol in different solvents.

Material:

Polyvinyl alcohol foil
Cold and hot water, acetone, ethanol, possibly methanol and other solvents
Beakers or test tubes, plastic pipettes

Before you begin with these experiments you have to discuss risks with your teacher!

Procedures:

Use a plastic pipette to put a droplet of cold water on the plastic's surface and watch what happens.

Is there any difference between the red and the transparent part of the plastic? Do they show different behavior in hot water?

Examine after that, in a beaker or a test tube, how a strip of polyvinyl alcohol foil behaves in different solvents.

[1] The manual is translated by kind permission of *Chemistry Teachers Resource Centre* (Kemilärarnas ResursCentrum), Sweden, 020108.

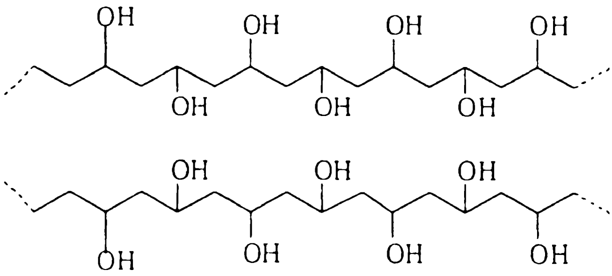

Fig. 1 The structural formula of polyvinyl alcohol

Task B.

Examine properties of a polyvinyl alcohol solution.

Material:

Polyvinyl alcohol solution, different solvents (e.g. ethanol, methanol, cyclohexane), pipette, beaker/test tube

Flashlight

Procedures:

Put some drops of polyvinyl alcohol solution into beakers/test tubes with the different solvents.

Or do the opposite: put some drops of solvent in a beaker with polyvinyl alcohol solution.

Which solvents make polyvinyl alcohol form a precipitate? Can you explain what happens?

Try to draw a picture of what it looks like in the water where the polymer (polyvinyl alcohol) is dissolved? Consider that you could make it form a precipitate again in some of the solvents!

Polyvinyl alcohol

Polyvinyl alcohol consists of carbon–hydrogen chains where a hydrogen atom on every second carbon atom is replaced by an OH-group. In the picture there are two chains (Fig. 1). A piece of a molecule chain in a ball and pin model is shown in Fig. 2.

Questions and Assignments:

1. Discuss why the polyvinyl alcohol has such different properties from polyethylene. In polyethylene the polymer molecules can be drawn like this. Every bend is a CH2-group (Fig. 3).

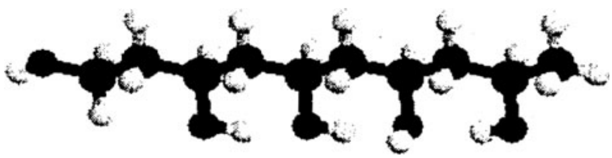

Fig. 2 A piece of a polyvinyl alcohol molecule in a ball and pin model

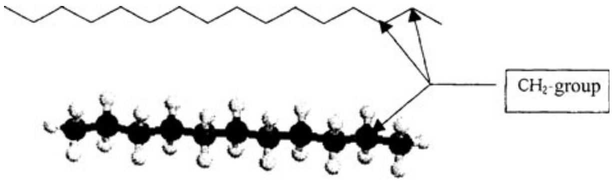

Fig. 3 Two models of polyethylene

2. The city council use polyvinyl alcohol in their washing bags. The germ-infested laundry is put in the bags and then tossed into the washing machine at the laundry. The dirty laundry therefore only has to be handled once. With your experiences from the laboratory exercise—what happens within the washing machine? (Does the red or the transparent polymer dissolve faster/more easily? Do you have any idea why?)
3. There must be more applications available for plastics that dissolve in water, mustn't there? For what product is it possible to use polyvinyl alcohol? Make suggestions and advertise your product!
4. In your solution there are polyvinyl alcohol molecules that on average consist of 1,600 monomers "pieces". Assume that you instead have molecules that are much bigger, with several thousand monomers. What do you think will happen to the solubility of such a polymer?

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