Chapter 15
Learning In and From Science Laboratories

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Introduction: The Science Laboratory in School Settings

Since the nineteenth century when schools began to teach science systematically, the laboratory became a distinctive feature of science education (Edgeworth and Edgeworth 1811 cited by Rosen 1954). After the First World War, with the rapid increase of science knowledge, the laboratory was used mainly as a means for confirmation and illustration of information learnt previously in a lecture or from a textbook. With the reform in science education in the 1960s, both in the USA and the UK, the ideal became to engage students with investigations, discoveries, inquiry and problem-solving activities. In other words, based on Lee Shulman and Pinchas Tamir's (1973) review, the laboratory became the core of the science learning process and science instruction. Over the years, the science laboratory was extensively and comprehensively researched and hundreds of research papers and doctoral dissertations were published all over the world (Hofstein and Lunetta 1982, 2004; Lazarowitz and Tamir 1994; Lunetta et al. 2007). This embrace of practical work, however, has been contrasted with challenges and serious questions about its efficiency and benefits (Hofstein and Lunetta 2004; Hodson 1993; Millar 1989). For many teachers (and often curriculum developers), practical work means simple recipe-type activities that students follow without the necessary mental engagement. The aimed-for ideal of open-ended inquiry, in which students have opportunities to plan an experiment, to ask questions, to hypothesise and to plan an experiment again to verify or reject their hypothesis, happens more rarely – and when it does, the learning outcome is much discussed.

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B.J. Fraser et al. (eds.), *Second International Handbook of Science Education*,
Springer International Handbooks of Education 24, DOI 10.1007/978-1-4020-9041-7_15,

This chapter reviews research on practical work in order to demonstrate not only its potential but also its challenges and problems. A main point to be made is that practical work is not a static issue but something that has evolved gradually over the years, and which is still developing. The development relates to changing aims for science education, to developments in understanding about science learning, to changing views and understanding of science inquiry and to more recent developments in educational technologies. To demonstrate this, we start with a review along historical lines, looking back at practical work research over the last 50 years during three periods: (1) 1960s to mid-1980s, (2) mid-1980s to mid-1990s and (3) the last 15 years. Following from this review, the second part of the chapter elaborates four different themes that summarise the state of affairs of practical work at the beginning of the twenty-first century and points towards new possibilities: how is practical work used by teachers, the influence of new technologies, 'metacognition' as a factor in laboratory learning and the issue of 'scientific argumentation' as a replacement for 'scientific method'.

Throughout the chapter, we use interchangeably the terms *practical work*, which is common in the UK context, and *laboratory work*, which is common in USA. A precise definition is difficult because these terms embrace an array of activities in schools, but generally they refer to experiences in school settings in which students interact with equipment and materials or secondary sources of data to observe and understand the natural world (Hegarty-Hazel 1990).

Fifty Years of Laboratory Work Research and Practice

1960s to Mid-1980s: Unfulfilled Ideals

This period is associated with the many curriculum projects that were developed to renew and improve science education. The projects started in the late 1950s with focus on updating and re-organising content knowledge in the science curricula, but soon reformists turned their attention towards *science process* as a main aim and organising principle for science education, as expressed by Sunee Klainin (1988) in Thailand:

> Many science educators and philosophers of science education (e.g. in the USA: Schwab, 1962; Rutherford and Gardner, 1970) regarded science education as a process of thought and action, as a means of acquiring new knowledge, and a means of understanding the natural world. (p. 171)

The emphasis on the processes rather than the products of science was fuelled by many initiatives and satisfied different interests. Some educators wanted a return to a more student-oriented pedagogy after the early reform projects which they thought paid too much attention to subject knowledge. Others regarded science process as the solution to the rapid development of knowledge in science and technology: mastering science processes was seen as more sustainable and therefore a way of making students prepared for the unknown challenges of the future. Most importantly, developments in cognitive psychology drew attention towards reasoning processes and scientific thinking. Psychologists such as Bruner, Piaget and Gagne helped to explain the thinking involved in the science process and inspired the idea that science teaching could help to develop this type of thinking in young people.

Although this development was found in its explicit form in the US, it was soon echoed in many other nations (Bates 1978; Hofstein and Lunetta 1982). Everywhere, the laboratory and practical work were put into focus. John Kerr (1963) in the UK suggested that practical work should be integrated with theoretical work in the sciences and should be used for its contribution to provide facts through investigations and, consequently, to arrive at principles that are related to these facts. This became a guiding principle in many of the Nuffield curriculum projects that were developed in the late 1960s and early 1970s.

The interest for practical work in science education research in this period is clearly demonstrated by Reuven Lazarowitz and Pinchas Tamir (1994) in their review on laboratory work. They identified 37 reviews on issues of the laboratory in the context of science education (Bryce and Robertson 1985; Hofstein and Lunetta 1982; Shulman and Tamir 1973). These reviews expressed a similarly strong belief regarding the potential of practical work in the curriculum, but also recognised important difficulties in obtaining convincing data on the educational effectiveness of such teaching. Not surprisingly, the only area in which laboratory work showed a real advantage (when compared to the nonpractical learning modes) was the development of laboratory manipulative skills. For conceptual understanding, critical thinking and understanding of the nature of science, there were little or no differences.

Lazarowitz and Tamir suggested that one reason for this relates to the use of inadequate assessment and research procedures. Quantitative research methods were not adequate for the research purpose but, at the time, qualitative research methods generally were disregarded in the science education community. Avi Hofstein and Vincent Lunetta (1982) identified several methodological shortcomings in research designs: insufficient control over laboratory procedures (including laboratory manuals, teacher behaviour and assessment of students' achievement and progress in the (laboratory); inappropriate samples and the use of measures that were not sensitive or relevant to laboratory processes and procedures.

Another issue was that teaching practice in the laboratory did not change as easily towards an open-ended style of teaching as the curriculum projects suggested. Teachers rather preferred a safer 'cookbook' approach (Tamir and Lunetta 1981). Alex Johnstone and Alasdair Wham (1982) claimed that educators underestimated the high cognitive demand of practical work on the learner. During practical work, the student has to handle a vast amount of information regarding the names of equipment and materials, instructions regarding the process, data and observations, thus causing overload on the student's working memory. This makes laboratory learning complicated rather than a simple and safe way towards learning.

Adding to this rather ominous picture, however, are some research studies and findings during this period that came to influence later developments more positively.

One area that was researched quite extensively concerns *intellectual development*. Jack Renner and Anthony Lawson (1973) and Robert Karplus (1977) (based on Jean Piaget 1970) developed the *learning cycle* that consisted of the following stages: *exploration*, in which the student manipulates concrete materials; *concept introduction*, in which the teacher introduces scientific concepts and, finally, *concept application*, in which the student investigates further questions and applies the new concept to novel situations. Many interpreters of Piaget's work (e.g. Robert Karplus 1977) inferred that work with concrete objects (provided in practical experiences) is an essential part of the development of logical thinking, particularly at the stage prior to the development of formal operations.

Another important contribution was made in the UK by Richard Kempa and John Ward (1975), who suggested a four-phase taxonomy to describe the overall process of practical work: (1) planning an investigation (experiment), (2) carrying out the experiment, (3) observations and (4) analysis, application and explanation. Tamir (1974) in Israel designed an inquiry-oriented laboratory examination in which the student was assessed on the bases of manipulation, self-reliance, observation, experimental design, communication and reasoning. These could serve as an organiser of laboratory objectives that could help in the design of meaningful instruments to assess outcomes of laboratory work. In addition, these had the potential to serve as a basis for continuous assessment of students' achievements and progress and also for the implementation of practical examinations (Ben-Zvi et al. 1976; Hofstein 2004; Tamir 1974).

Mid-1980s to Mid-1990s: The Constructivist Influence

During the period from the mid-1980s to the mid-1990s, practical work was challenged in two different ways. One was related to an increasing awareness amongst science education researchers of a failure of establishing the intended pedagogy in the reform projects from the previous period. This was expressed by Paul Hurd (1983) and Robert Yager (1984), who reported laboratory work in schools tended to focus on following instructions, getting the right answer or manipulating equipment. Students failed to achieve the conceptual and procedural understandings that were intended. Very often, students failed to understand the relationship between the purpose of the investigation and design of the experiments (Lunetta et al. 2007). In addition, there was little evidence that students were provided with opportunities and time to wrestle with the nature of science and its alignment with laboratory work. Students seldom noted the discrepancies between their own concepts, their peers' concepts and the concepts of the science community (Eylon and Linn 1988; Tobin 1990). In sum, practical work meant manipulating equipment and materials, but not ideas.

The other challenge involved the theoretical underpinning of laboratory work. The process approach was challenged by a new perspective on science education known as *constructivism*. The constructivist area started in the late 1970s with increasing criticisms against the Piagetian influence on science education. New voices argued that too much attention had been paid towards general cognitive skills in science learning and that science educators had missed the importance of students' conceptual development (e.g. Driver and Easley 1978).

The effects of this criticism can be followed in the UK in the aftermath of the Nuffield curriculum reform projects, which had contributed towards a strong foothold for the science laboratory. John Beatty and Brian Woolnough (1982) reported that 11–13-year olds typically spent over half of their science lesson time doing practical activities. This was also a period of the Assessment for Performance Unit (APU), a national assessment project within a process-led theoretical framework (Murphy and Gott 1984), which later influenced the national curriculum and its aligned assessment system.

During the 1980s, researchers started to question this practice and its theoretical underpinning in the light of philosophical and sociological accounts associated with constructivism (Millar and Driver 1987). The argument was that the entire science education community had been misled by a naïve empiricist view of science, referred to by Robin Millar (1989) as the Standard Science Education (SSE) view. The SSE view presents science as a simple application of a stepwise method, and further relates these steps to particular intellectual and practical skills. In other words, by having the right skills and by applying 'the scientific method', anyone can develop scientific knowledge. With the denial of this view of science inquiry, science educators were in need of an alternative, but finding this took some time and required a series of developments.

Two different attempts to develop alternative theoretical platforms appeared on the UK scene in the late 1980s and early 1990s. The first attempt had its inspiration from Michael Polanyi's (1958) concept of 'tacit knowledge'. This approach had similarities to the process approach, but denied the possibility of identifying individual processes (Woolnough and Allsop 1985). Rather, it was claimed that science is like a 'craftsmanship' and that investigations should be treated like a 'holistic process' based on understandings that cannot be explicitly expressed. The belief was that inquiry at school with a trained scientist (i.e. the teacher) developed this craftsmanship, and made students generally better problem solvers (Watts 1991). Retrospectively, we can see this approach as avoiding the challenge of identifying what it really means to do science by making the process hidden and mysterious.

The other theoretical approach also held on to science as a problem-solving process, but avoided the mistake in previous theories of focusing too strongly on skills. Richard Gott and Sandra Duggan (1995) claimed that the ability to do scientific inquiry was based fundamentally on procedural knowledge (i.e. understanding required in knowing how to do science). When scientists carry out their research, they have a toolkit of knowledge about community standards and what procedures to follow to satisfy these. The aim of science inquiry is not only to find new theories, but also to establish evidence that a theory is 'trustworthy'. They therefore claimed that students should be taught procedural understanding along with conceptual understanding, and then get practice in problem solving based on these two components.

At the end of the second period, constructivism was well established in science education. The teaching of skills and procedures of scientific inquiry had lost much of its status as science educators paid more interest to conceptual learning. One influential idea was the use of Predict-Observe-Explain (POE) tasks (Gunstone and Mitchell and the Children Science Group 1988). In these tasks, observations in the laboratory are used to challenge students' ideas and help to develop explanations in line with the correct scientific theories. Richard Gunstone (1991) and Richard White (1991) also made another statement about of the constructivist message for the science laboratory teaching. In particular, it was claimed that all observations are theory-laden. This means that doing practical work is no guarantee for adopting the right theoretical perspective. Students need to reflect on observations and experiences in light of their conceptual knowledge. Kenneth Tobin (1990) wrote that: 'Laboratory activities appeal as a way of allowing students to learn with understanding and, at the same time, engage in the process of constructing knowledge by doing science' (p. 405). To attain this goal, he suggested that students should be provided with opportunities in the laboratory to reflect on findings, clarify understandings and misunderstandings with peers and consult a range of resources that include teachers, books and other learning materials. His review reported that such opportunities rarely exist because teachers are so often preoccupied with technical and managerial activities in the laboratory. Richard Gunstone and John Baird (1988) pointed towards the importance of metacognition for this to happen. White (1991) also argued that the laboratory helps students in building up 'episodic' memories that can support later development of conceptual knowledge.

Period After Mid-1990s: A New Area of Change

During the last 15 years, we have seen major changes in science education. These were caused partly by globalisation and rapid technological development, which call for educational systems with high-quality science education to meet international competition and develop the knowledge and competencies needed in modern society. In the USA, we have seen developments regarding 'standards' for science education (NRC 1996, 2005) that provide clear support for inquiry learning both as content and as high-order learning skills that include, in the context of the laboratory, planning an experiment, observing, asking relevant questions, hypothesising and analysing experimental results (Rodger Bybee 2000). In addition, we observed internationally that there has been a high frequency of curriculum reforms. A central point has been to make science education better adapted to the needs of all citizens (AAAS 1991).

It is recognised that citizens' needs include more than just scientific knowledge. In everyday life, science is often involved in public debate and used as evidence to support political views. Science also frequently presents findings and information that challenge existing norms and ethical standards in society. Mostly it is cutting-edge science and not established theories that are at play. For this reason, it does not help to know textbook science, but rather it is necessary to have knowledge *about* science. Robin Millar and Jonathan Osborne (1999) suggested in this context that citizens need to understand principles of scientific inquiry and how science operates at a social level. The natural question, of course, is to what degree and in what ways the science laboratory can help to provide students with such understanding.

Another area of change in the recent period has been further development of constructivist perspectives into sociocultural views of learning and of science. The sociocultural view of science emphasises that science knowledge is socially constructed. Scientific inquiry, accordingly, is seen to include a process in which explanations are developed to make sense of data and then presented to a community of peers for critique, debate, and revision (Duschl and Osborne 2002). This re-conceptualisation of science from an individual to a social perspective has fundamentally changed the view of experiments as a way of portraying the scientific method. Rather than seeing the procedural steps of the experiment as the scientific method, practical work is now valued for the role that it plays in providing evidence for knowledge claims according to Rosalind Driver, John Leach, Robin Millar and Philip Scott (Driver et al. 2000). The term scientific method, as such, has lost much of its valour (Jenkins 2007).

The *sociocultural* view of learning is based on a Vygotskian perspective pointing towards the role of social interaction in learning and thinking processes (Vygotsky 1978). It is believed that thinking processes originate from socially mediated activities, particularly through the mediation of language. As a consequence, science learning is seen as socialisation into a scientific culture (Driver et al. 2000). Students therefore need opportunities to practise using their science ideas and thinking through talking with each other and with the science teacher (Scott 1998).

All these changes have obvious relevance for practical work. Rather than training science specialists, the laboratory should now help the average citizen to understand *about* science and to develop skills useful in evaluating scientific claims in everyday life. Rather than promoting the scientific method, the laboratory should focus on how we know what we know and why we believe certain statements rather than competing alternatives (Duschl and Grandy 2007). The socialcultural learning perspective also provides reasons to re-visit group work in the school laboratory. Most importantly, the current changes have finally produced an alternative to the science process approach and the SSE-view (Millar 1989) established 50 years ago. We now find a new rationale for understanding science inquiry and how this can link with laboratory work at school.

Emerging Themes

In the remainder of this chapter, we look into four themes that further elaborate the current situation for laboratory work in science education research and practice.

Teachers' and Students' Practice in Science Laboratories: How Are Laboratories Used?

To what degree has the use of practical work changed at schools? In this section, we look at research into how laboratories are used by teachers and students, as well as the nature of laboratory activities and facilities.

On the basis of a comprehensive study of the implementation of the laboratory in schools in British Columbia (Gardiner and Farrangher 1997), it was found that, although many biology teachers articulated philosophies that appeared to support a hands-on investigative approach with authentic learning experiences, the classroom practices of those teachers did not generally appear to be consistent with their stated philosophies. Several studies have reported that very often teachers involve students principally in relatively low-level, routine activities in laboratories and that teacher–student interactions focused principally on low-level procedural questions and answers. Ron Marx et al. (1998) reported that science teachers often have difficulty in helping students to ask thoughtful questions, design investigations and draw conclusions from data. Similar findings were reported regarding chemistry laboratory settings (De Carlo and Rubba 1994). More recently, Ian Abrahams and Robin Millar (2008) in the UK investigated the effectiveness of practical work by analysing a sample of 25 typical science lessons involving practical work in English secondary schools. They concluded that the teachers' focus in these lessons was predominantly on making students manipulate physical objects and equipment. Hardly any teacher focused on the cognitive challenge of linking observations and experiences to conceptual ideas. Neither was there any focus on developing students' understanding of scientific inquiry procedures. A comprehensive and long-term study on the use (and objectives) of laboratories in several EU countries was conducted by Marie Sere (2002). In this research, based on 23 case studies, it was found that laboratory work was perceived as an essential ingredient of the experimental sciences. However, it was also found that the objectives stated for practical work (including conceptual understanding, understanding of theories and laws and high-order learning skills) were too numerous and demanding to be implemented by the average science teacher in their respective classrooms.

These findings echo the situation at any time in the history of school science. Basic elements of teachers' implementation of practical work do not seem to have changed over the last century; students still carry out recipe-type activities that are supposed to reflect science procedures and teach science knowledge, but which in general fail on both. This is not to say everything is the same. Science education has moved forwards during the last decades with associated improvement in teachers' professional knowledge and classroom practice, but this improvement has not sufficiently caught up with the challenges of using laboratory work in an efficient and appropriate way. Teachers still do not perceive what is required to make laboratory activities serve as a principal means of enabling students to construct meaningful understanding of science, and they do not engage students in laboratory activities in ways that are likely to promote the development of science concepts. In addition, many teachers do not perceive that helping students to understand how scientific knowledge is developed and used in a scientific community is an especially important goal of laboratory activities for their students.

Today's conclusion has therefore not changed substantially from what Brian Woolnough and Terry Allsop (1985) claimed:

> Teachers at present are ill prepared to teach effectively in the laboratory. A major reason is that most science teachers have themselves brought-up on a diet of content dominated cookery book-type practical work and many have got in their habit of propagating it themselves. (p. 80)

Aligned with this situation for teachers, we find a matching picture in students' experiences and laboratory teaching materials. Attempts have been made to develop protocols for analysing laboratory activities (Lunetta and Tamir 1979; Millar et al. 1999). Darrell Fisher et al. (1999) used Lunetta and Tamir's protocol to analyse laboratory guides in Australia. The analyses suggest that, to date, many students engage in laboratory activities in which they follow recipes and gather and record data without a clear sense of the purposes and procedures of their investigation and their interconnections. Daniel Domin (1998) in the USA found that students are seldom given opportunities to use higher-level cognitive skills or to discuss substantive scientific knowledge associated with investigations, and many of the tasks presented to them continue to follow a cookbook approach that concentrates on the development of lower-level skills and abilities.

The reviews discussed earlier in this chapter revealed a mismatch between the goals articulated for the school science laboratory and what students regularly do during those experiences. Ensuring that students' experiences in the laboratory are aligned with stated goals for learning demands that teachers explicitly link decisions regarding laboratory topics, activities, materials and teaching strategies to desired outcomes for students' learning. The body of past research suggests that far more attention to the crucial roles of the teacher and other sources of guidance during laboratory activities is required, and that researchers must also be diligent in examining the many variables that interact to influence the learning that occurs in the complex classroom laboratory.

Developing Inquiry and Learning Empowering Technologies

In the early 1980s, digital technologies became increasingly visible in school laboratories and were recognised as important tools in school science (Lunetta 1998). Much evidence now documents that using appropriate technologies in the school laboratory can enhance learning of important scientific ideas. Inquiry empowering technologies (Hofstein and Lunetta 2004) have been developed and adapted to assist students in gathering, organising, visualising, interpreting and reporting data. Some teachers and students also use new technology tools to gather data from multiple trials and over long time intervals (Dori et al. 2004; Friedler et al. 1990; Krajcik et al. 2000; Lunetta 1998). When teachers and students properly use inquiry-empowering technologies to gather and to analyse data, students have more time to observe, reflect and construct conceptual knowledge that underlies their laboratory experiences. Using appropriate technology tools can enable students to conduct, interpret and report more complete, accurate and interesting investigations. Carla Zembal-Saul et al. (2002) suggested that such tools can also provide media that support communication, student–student collaboration, the development of a community of inquirers in the laboratory classroom and beyond and the development of argumentation skills.

Two studies illustrate the potential effectiveness of particular technology in school science. Marry Nakleh and Joe Krajcik (1994) investigated how students' use of chemical indicators, pH meters and microcomputer-based laboratories (MBL) affected their understanding of acid-base reactions. Students who used computer tools in the laboratory were more able to draw relevant concept maps, describe the acid-base construct and argue about the probable causes of why their graphs formed as they did. Judy Dori et al. (2004) developed a high school chemistry unit in which students pursued chemistry investigations using integrated desktop computer probes. Using a pre-post design, these researchers found that students' experiences with the technology tools improved their ability to pose questions, use graphing skills and pursue scientific inquiry more generally. To sum up, there is some evidence that integrating information and communication technology (ICT) tools into the science laboratory is promising. However, this development is still at an early stage. The level at which ICT is used in laboratory classes varies a lot. We assume that, in the future, this will expand. In addition, it is expected that ICT will be used to achieve more integration between practical work and computer-based simulations. This is an area that needs more research regarding its educational effectiveness.

The Development of Metacognitive Skills in the Science Laboratory

As we have seen, the high hopes for developing thinking skills in the laboratory failed partly because of inadequate alignment of learning theories with school science practice. One factor that has brought new understanding to this area is *metacognition*, which refers to higher-order thinking skills that involve active control over the thinking processes involved in learning. Activities such as planning how to approach a given learning task, monitoring comprehension and evaluating progress towards the completion of a task are metacognitive in nature (Livingston 1997). There is no single definition used for metacognition and its diverse meanings are represented in the literature that deals with thinking skills. Gregory Schraw (1998), for example, presents a model in which metacognition includes the two main components: knowledge of cognition and regulation of cognition. Knowledge of cognition refers to what individuals know about their own cognition or about cognition in general. It includes at least three different kinds of metacognitive knowledge: declarative knowledge about oneself as a learner and about factors that influence one's performance (knowing 'about' things); procedural knowledge about doing things in terms of having heuristics and strategies (knowing 'how' to do things) and conditional knowledge about when to use declarative and procedural knowledge and why (knowing the 'why' and 'when' aspects of cognition). Regulation of cognition refers to a set of activities that help students to control their learning. Although a number of regulatory skills have been described in the literature, three essential skills are included in all accounts: planning involves the selection of appropriate strategies and the allocation of resources that affect performance; monitoring refers to one's online awareness of comprehension and task performance and evaluating refers to appraising the products and efficiency of one's learning. Other researchers such as John Baird and Richard White (1996) have made different divisions and categorisations of metacognition.

When applied to science learning generally, metacognition is related to meaningful learning, or learning with understanding (Baird and White 1996; Rickey and Stacy 2000; White and Mitchell 1994), which includes being able to apply what has been learnt in new contexts (Kuhn 2000). Metacognition is also related to developing *independent learners* (NRC 1996, 2005), who typically are aware of their knowledge and of the options to enlarge it. One key component is *control* of the problem-solving processes and the performance of other learning assignments. Researchers link this *control* to the student's *awareness* of his or her physical and cognitive actions during the performance of the tasks (Baird 1998; White 1998). Another element is the student's *monitoring* of knowledge (Rickey and Stacy 2000). Learners who properly monitor their knowledge can distinguish between the concepts that they know and the concepts that they do not know and can plan their learning effectively.

The link between metacognition and scientific inquiry seems to be obvious. Scientists depend on their ability to control reasoning when working out new ideas and weighing up the evidence confirming or contrasting these. Dianne Kuhn et al. (2000) argue that students who experience inquiry activities in a similar way 'come to understand that they are able to acquire knowledge they desire, in virtually any content domain, in ways that they can initiate, manage, and execute on their own, and that such knowledge is empowering' (p. 496).

Baird and White (1996) claim that four conditions are necessary in order to induce the personal development entailed in directing purposeful inquiry: time, opportunity, guidance and support. The science teacher should provide students with experiences, opportunities and the time to discuss their idea about the problems that they have to solve during the learning activity. The role of the teacher is to provide continuous guidance and support to ensure that students develop control and awareness over their learning. This can be accomplished by providing students with more freedom to select the subject of their project and to manage their time and their actions in the problem-solving process. The social learning perspectives described earlier also draw attention to the support that students might get from peers in the laboratory. Students can clarify their ideas and the way they had developed them, in order to explain those ideas to their classmates. Moreover, laboratory experiences in which students discuss ideas and make decisions can present many opportunities for teachers to observe students' thinking as they negotiate meaning with their peers. Carefully observing students' actions and listening to their dialogue creates opportunities for teachers to focus questions and make comments within learners' zones of proximal development (Duschl and Osborne 2002; Vygotsky 1978, 1986) that can help the students to *construct* understandings that is more compatible with the concepts of expert scientific communities.

An application of these perspectives is demonstrated in a chemistry laboratory programme titled Learning in the Chemistry Laboratory by the Inquiry Approach was developed by Hofstein et al. (2004) at the department of Science Teaching at the Weizmann Institute of Science in Israel. For this programme, about 100 inquiry-type experiments were developed and implemented in eleventh and twelfth grade chemistry classes in Israel. A two-phased teaching process was used, including a guided pre-inquiry phase followed by a more open-ended inquiry phase. Based on their research, Mira Kipnis and Avi Hofstein (2008) have linked metacognitive skills (based on the model of Schraw 1998) to various stages of the inquiry-oriented experiments. First, whilst asking questions and choosing an inquiry question, the students revealed their thoughts about the questions that were suggested by their partners and about their own questions. In this stage, *metacognitive declarative knowledge* is expressed. Second, whilst choosing the inquiry question, the students expressed their *metacognitive procedural knowledge* by choosing the question that leads to conclusions. Third, whilst performing their own experiment and planning changes and improvements, the students demonstrate the *planning* component of *regulation of cognition*. Fourth, at the final stage of the inquiry activity, when students write their reports and have to draw conclusions, they utilise *metacognitive conditional knowledge*. Fifth, during the whole activity, students made use of the *monitoring* and *evaluating* components concerned with *regulation of cognition.* In this way, they examined the results of their observations in order to decide whether the results are logical.

Scientific Argumentation and Epistemologies – A New Rationale for Practical Work

When Rosalind Driver et al. (2000) presented their introduction to argumentation in science education, they quickly pointed towards the relevance for practical work. They saw argumentation as correcting the misinterpretation of the scientific method that has dominated much of science teaching in general and practical work in particular. Rather than focusing on the stepwise series of actions carried out by scientists in experiments, they suggested a focus on the *epistemic practice* involved when developing and evaluating scientific knowledge. Gregory Kelly and Richard Duschl (2002) similarly present science learning as *epistemic apprenticeship*: the appropriation of practices associated with producing, communicating and evaluating knowledge. Within this framework, practical work becomes a way of introducing students to *community standards* applied by scientists. We sense two overlapping learning aims: students should understand the scientific standards and their guiding epistemologies; and students should be able to apply these standards in their own argumentation.

We find many ways of approaching research into students' epistemological understanding and argumentation skills. One contribution comes from psychologists who identify scientific argumentation as the key element of scientific thinking (Kuhn et al. 1988). Dianne Kuhn et al. work from the perspective that certain reasoning skills related to argumentation are domain general. People who are good at scientific argumentation are able to (1) think *about* a scientific theory, rather than just think *with* it; (2) encode and think about evidence and distinguish it from theory and (3) put aside their personal opinions about what is 'right' and rather weigh a theoretical claim against the evidence. Kuhn (2000) demonstrates how these abilities develop naturally from childhood to adulthood, but also that the quality varies amongst people. Scientists are good at this thinking because it is embedded in their culture and, importantly, explicit training in the science laboratory seems to help (Kuhn et al. 2000).

Another contribution comes from research on *procedural knowledge* (Gott and Duggan 1995) presented earlier in this chapter. Glen Aikenhead (2003) illustrates the relevance in society and work life of understanding issues related to the way in which scientists use data as evidence to draw conclusions. The underlying idea is that knowledge about data and the use of data developed in the laboratory can be transferred to these situations. One study of university students supports this (Roberts and Gott 2007), but little evidence yet exists for younger pupils.

Several research studies indicate that the development of students' argumentation skills and science epistemologies is rather complicated. Students, for example, might hold some beliefs about professional science and very different beliefs about their own practices with inquiry at school (i.e. students have one set of *formal* epistemologies and another set of *personal* epistemologies) (Hammer and Elby 2002; Sandoval 2005). Many years of teaching 'ideas and evidence' in the UK through practical investigations illustrate this complexity (Driver et al. 1996). Per Kind (2003) suggested that the overall picture has been that students become good at doing specific types of routine experiments, and solve these using school-based strategies rather than a general understanding of formal scientific epistemologies. Jim Ryder and John Leach (2005) assume that one reason for these problems is that learning objectives are not sufficiently made explicit to the students. Most students are able to articulate the learning objectives following a lesson focused on science content knowledge, even if they struggle to understand the concepts. However, when the objective of a lesson has an epistemological or procedural focus, students are much more unclear about what they are intended to learn.

Many writers have also related the problems with developing epistemological views and practices in school science to the teachers' background and competencies. Maher Hashweh (1996) has found connections between the epistemological beliefs expressed by teachers and their preferred ways of teaching, but the relationship is not simple. It is teachers with naïve epistemological beliefs who most easily support teaching ‘real science’ in the school laboratory. In addition, it is suggested by Nam-How Kang and Carolyn Wallace (2005) that such teachers more easily view students as ‘young scientists’ who are able to construct meanings on their own. For a teacher with a more sophisticated epistemological understanding of science, the relationship is more complicated. They tend to disconnect ‘real science’ from ‘school science’ and more rarely allow their epistemological beliefs to be reflected in their teaching practice, as shown in studies conducted by John Barnett and Derek Hodson (2001) and by Nam-How Kang and Caroline Wallace (2005). Teachers with sophisticated epistemologies also seem to separate science from students, treating students as more as ‘spectators’ of science (e.g. Randy Yerrick et al. 1998).

Pilar Jimenez-Aleixandre et al. (2000) suggested that a better understanding of how practical work might contribute towards the development of students’ epistemological understanding and argumentation skills could involve a closer look at the ‘teaching ecology’ of the laboratory. It is strongly argued that bringing argumentation into science classrooms requires the enactment of contexts that transform them into knowledge-producing communities, which encourage dialogic discourse and various forms of cognitive, social and cultural interactions amongst learners (Duschl and Osborne 2002; Newton et al. 1999). An ecology that promotes this practice is created through the social and physical environment (Wolff-Michael Roth et al. 1999), the laboratory tasks (Clark Chinn and Betina Malhotra 2002) and the organisation principles used by the teacher (Issam Abi-El-Mona and Fouad Abd-El-Khalick 2006; Phil Scott 1998). A reconsideration of all these factors is therefore needed for the science laboratory to contribute meaningfully and effectively towards the new learning goals.

Concluding Remarks

The biggest challenge for practical work, historically and today, is to change the practice of ‘manipulating equipment not ideas’. The typical laboratory experience in school science is a hands-on but not a minds-on activity. This problem is related to teachers’ fear of loosing control in the classroom and giving students more responsibility for their learning. Also, the current situation can be blamed on assessment practices that do not pay enough attention to higher-order thinking and a long tradition of developing foolproof laboratory tasks that guide students through activities without requiring deep reflection. This chapter has demonstrated a relationship between these problems in practical work and commonsense ideas about science inquiry as a stepwise method.

It has taken science education research a long time to reveal this practice, analyse its underlying rationale and present alternatives. The development has required a move away from quantitative data-collection methods, which are not sensitive to students’ learning in the laboratory, towards more authentic ways of studying what actually goes on in the laboratory. It has also required a thorough analysis of the nature of science inquiry and what makes someone good at doing it. The alternatives that are prominent today not only combine sociocultural perspectives on science and learning, but also link to new aims for school science as an important provider of skills and knowledge for citizenship.

At the turn of the century, we might claim that science education is in a better position than ever before for developing meaningful and appropriate practices for laboratory work. The situation is most promising because of the results and knowledge that have been accumulated and achieved. There are many places to start in developing new laboratory teaching strategies and professional development provisions for teachers. These and other tasks call for science education researchers to engage with practical work and to help to develop this area further.

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