What is the Purpose of this Experiment?
Or Can Students Learn Something from Doing Experiments?

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Abstract: Historically there have been many claims made about the value of laboratory work in schools, yet research shows that it often achieves little meaningful learning by students. One reason, among many, for this failing is that students often do not know the “purposes” for these tasks. By purposes we mean the intentions the teacher has for the activity when she/he decides to use it with a particular class at a particular time. This we contrast with the “aims” of a laboratory activity, the often quite formalised statements about the intended endpoint of the activity that are too often the “opening lines” of a student laboratory report and are simply the “expected” specific science content knowledge outcomes—not necessarily learnt nor understood. This paper describes a unit of laboratory work which was unusual in that the teacher’s purpose was to develop students’ understanding about the way scientific facts are established with little expectation that they would understand the science content involved in the experiments. The unit was very successful from both a cognitive and affective perspective. An important feature was the way in which students gradually came to understand the teacher’s purpose as they proceeded through the unit.

The research we report here focuses on the work of a highly informed and experienced science teacher (the first author) who sought to address her concerns about laboratory work. As we explain below, the study was a collaborative one in which the teacher and the researchers worked closely together as a research team, and the voices of both teacher and researchers are presented.

There have been many studies of science laboratory work over many years, and many reviews of this research (see, e.g., Kerr, 1964; Hofstein & Lunetta, 1982; Lazarowitz & Tamir, 1994; Lunetta, 1998). Given the significance attached to laboratory work in science curriculum statements, textbooks, teacher education programs, and so on, this research attention is not surprising. Laboratory work is almost ubiquitously seen as being of great importance to science education, by some as almost the defining characteristic of this component of the school...
curriculum. However, research on aspects of laboratory work and its consequences does not provide strong support for this view. Some studies have even concluded that the fundamental concern of many students while in the laboratory is completion of the task, and that this concern can overwhelm any serious learning possibilities (see, e.g., Edmondson & Novak, 1993; Berry, Mulhall, Loughran, & Gunstone, 1999a, 1999b). There are issues of research purpose, research methodology, research context, teacher and student perceptions, etc. embedded in the failure of past investigations to substantiate many of the claims of advocates of this mode of classroom work (Lazarowitz & Tamir, 1994, pp 120–122).

Even so, many studies that have focused on purposes, uses, and learning from laboratories have significant things to say, and draw conclusions of relevance to this study. Johnstone and Wham (1982) noted that laboratory work often cognitively overloads students with too many things to recall while Gunstone and Champagne (1990) argued that laboratory work could successfully be used to promote conceptual change if small qualitative laboratory tasks are used. Such tasks aid in students’ reconstructing their thinking as less time is spent on interacting with apparatus, instructions, and recipes, and more time spent on discussion and reflection. Hodson (1990) described laboratory work as often being dull and teacher-directed, and highlighted the fact that students often failed to relate the laboratory work to other aspects of their learning.

Renner, Abraham, and Birnie (1985a, 1985b) examined ways of making the laboratory an active learning environment for students and found that discussion was pivotal. The importance of this finding is in ways enhanced by the observation that a large number of science teachers struggle with discussion as a pivotal concept in laboratory work. In fact, Watts and Ebutt (1988) found that many students preferred laboratory work which offered them opportunities to better direct their enquiries; clearly, discussion is important in helping students to clarify their thinking and this is especially so in self-directed enquiry. Conclusions such as these resonate well with the individual impressions of many teachers about the role and place of science laboratory work; teachers often identify with this research through personal experience. A consequence of this, for some science teachers, is a continual search for ways of addressing their concerns about science laboratory work, of seeking alternative approaches to the use of the laboratory that might lead to consequences more in line with the claims often made for the laboratory. This paper examines one such exploration.

“Aim” and “Purpose” as Different in Laboratory Work

One issue that is central to our thinking is the concept of “purpose” as applied to consideration of laboratory work. The essence of our meaning for “purpose” is the intentions the teacher has for the activity when she/he decides to use it with this class at this time. Generally then, our view of purpose refers to the teacher’s pedagogical intentions—the teacher’s reasons for using a particular laboratory activity and the way the activity is organized, how the activity “fits in” to the unit of work at that time, and how the activity is intended to result in planned student learning.

In terms of our thinking, the purpose then is significantly different from the “aim,” the statement that is usually developed or given to the class at the beginning of the activity, and is commonly reproduced in the (often ritualized) student report at the end of the activity. The aim refers to the specific science learning outcomes of the activity. For example, while a laboratory activity might have as its “aim” that Newton’s Law be verified, or to determine the effect of light on germinating seeds, the “purpose” will be broader and more substantive, and include why the activity comes at this point in the teaching sequence, how the teacher intends the activity to link with other class experiences before and after, why the activity is of this form (e.g., for the first of
our example aims above, verification rather than inducing the law from data). That is, while the “aim” can reasonably be seen as something that determines what is done in the activity itself, the “purpose” is about how this activity is intended to result in learning, how and why the activity links with the whole science experience at the time.

The Origins of This Study

The dual title of this paper reflects its origins as a collaborative piece written by an experienced practising science teacher (Christina) at a Catholic all-girls’ high school in Melbourne, Australia, and researchers at a nearby university. For convenience, we refer here to “teacher” and “researchers” to indicate Christina and the group of academics even though this unreasonably implies the teacher is not a researcher.

Rop (1999) recounts a conversation with a successful high school chemistry student: “She explained that success is quite painlessly achieved by a process of ‘doing the work’ and ‘getting good grades on tests’” (p. 221). Many teachers would identify with this type of student response to school science. In a similar fashion, Christina, disillusioned with her students’ lack of learning from laboratory work but aware that they usually enjoyed it, decided to challenge this type of view. She designed a unit for her year 10 class that involved the students planning and conducting some chemistry experiments and then writing about them in such a way that other students could repeat the same experiments. Her purpose (as with “purpose” used in the sense described above) was to develop her students’ understanding about the role of experimental work in establishing scientific knowledge—in particular the roles of communication and replication of experimental work in the acceptance of knowledge by the scientific community. An unusual feature of this laboratory unit was that the students had very little prior relevant chemistry content knowledge (specific propositional knowledge relating to the phenomena to be examined in the experiments). The researchers, who at the time were involved in a 3-year research project exploring student learning from laboratory work, were invited by Christina to observe and investigate the outcomes of the unit when she used it with her class. The first part of this paper’s title summarizes the researchers’ focus which was to determine whether Christina’s students made the link between the tasks involved in the unit and her purpose. The second part of the title underscores Christina’s hope that, contrary to her previous experience, her students would actually learn something from the unit of work.

The paper itself is constructed in such a way as to reflect the voices of both the researchers and the voice of the teacher, as the unit, and the investigation of the unit, progressed. From the researchers’ perspective, we explain how the investigation of the unit related to the research project in which we were involved, the purposes of the investigation, how it was conducted, its outcomes and implications. Christina explains how she came to develop the unit, her experience of teaching the unit and her reaction to the research outcomes. We portray these two different voices by presenting that of Christina in Italics. We begin this dual voice structure by presenting relevant antecedent thinking of first, Christina, and then the researchers.

The Rubric and Reality of Laboratory Work in School Science

Most laboratory work in school science follows a familiar rubric. Students are presented with an aim, a suggested hypothesis, steps for carrying out an experiment (method or procedure), observations and/or measurements that should be recorded, and questions that lead to the conclusion that is to be drawn from the experiment (see e.g., Stannard and Williamson, 1992). Teachers assume that in following this rubric students will learn particular content (e.g., that
temperature affects the rate of a chemical reaction). Indeed this is generally the teacher’s main intent in devoting a lesson to a particular experiment: that students will learn (and believe) a particular scientific “fact” because they “see” it in the laboratory exercise.

Teachers may have other intentions for such activities in addition to this. For example, they may believe that in conducting such an experiment, students will be following a “scientific method,” similar to that which led to the original discovery of the relevant fact. In other words, teachers may hope that, by following the rubric, students will learn how scientists go about their business of understanding the world, and will understand how scientific knowledge is produced or discovered and that which makes it “science.”

Research suggests that practical work may not be an effective means for students to learn science content. For example, based on the

Empirical evidence concerning the efficacy of practical work as a way of learning scientific knowledge . . . it cannot be argued that practical work is superior to other methods and, on occasions, it seems to be somewhat less successful (Hodson, 1993, p. 94). . . . [T]he standard practical experiments designed to lead students to the ‘right result’ . . . [do] not lead to a good understanding of the underlying theory . . . (Woolnough, 1991, p. 4). Where displaying and justifying scientific theory is the aim . . . teacher demonstrations may be more effective than practical activities undertaken by students. (Woolnough & Allsop, 1985, cited in Millar, 1991, p. 44)

The literature also raises many questions about the possibility that the type of practical work carried out in school science can provide students with a valid picture of how scientific knowledge is produced. Most practical work is based on the assumption that observing is a simple matter of receiving information via the senses, and does not involve any cognitive or other processing by the observer. Consequently all observers can make the same, totally objective, observations during an experiment. This ‘positivist’ view leads to a particular view of the nature of scientific knowledge.

Often experiments are regarded by teachers as revealing meaning . . . . As a consequence, the implicit curriculum message is that scientific theory is a body of authoritative knowledge, revealed and authenticated by infallible observation and conclusive experimentation. (Hodson, 1993 p. 126)

As a view of the way scientific knowledge is produced, this is inadequate.

. . . [S]eeing the same . . . involves (two people) sharing knowledge and theories about x . . . . There is a sense in which seeing is a theory laden undertaking. Observation of x is shaped by prior knowledge of x. (Hanson, 1958, pp. 18–19)

Thus, observation is not a matter of passively receiving information about the world. People will see different things according to their expectations, and the theoretical frameworks they hold. In pretending otherwise, school science leaves out many crucial aspects of scientific activity, including the fallibility, the passion, the commitment, and the creativity involved.

Questioning the Point of Laboratory Work: The Teacher’s Perspective

I (Christina) became disillusioned with laboratory work as an effective tool for learning science content within a few years of beginning teaching. A short period of research gave me
time to reflect on what school laboratory work conveyed about the nature of science, and when I returned to teaching this became a focus for my thinking (as has also been the case for many science philosophers, see e.g., Alters, 1997; Eflin, Glennan, & Reisch, 1999). To my earlier dissatisfaction with practical work as an effective learning tool, I had now added concern about the inductivist philosophy of science that implicitly underlies most school experiments.

A central problem arises from the acceptance by most philosophers of science (including Popper) that all observations are theory laden. (Millar, 1991, p. 46)

In the same way as any scientist, students will see what their prior theories lead them to expect. More significantly, they will not make the meaning that we as teachers expect them to make of experimental evidence until they have already grasped the theoretical framework that allows them to “see” the evidence. I am concerned that in the absence of such meaning, students may reduce laboratory work to a game of “correct answers” and “what should happen,” and reduce science itself to a mystical process. Because students themselves cannot “see” in an experiment what “science” says they should, they may conclude that scientists operate by a process that is unattainable by others. The knowledge that scientists derive is perceived to be fundamentally at odds with what ordinary people see and know, and science appears to have more to do with revelation and magic, than with rationality. Without conceding the excessive rationalist claims of positivism, it seems to me that we fail young people if we do not give them insight into the ways that science differs from other forms of human knowledge and, with that, the criteria by which to judge the validity of scientific claims.

One of the most important features of scientific knowledge is that scientific “facts” are those observations that everyone can agree are true. Such “facts” are most easily established by conducting controlled experiments, usually in laboratories. Experimental findings are published in the scientific literature where they are open to challenge and verification by other members of the community of scientists. Where experimental findings are verified, they become accepted as fact.

The “theory ladenness of observation” means that the whole community of scientists can accept something as fact, which can later be shown to be untrue. Nonetheless, what distinguishes science from other forms of knowledge is the reproducibility of observations or experimental results. The publication and communication of experimental findings is a crucial part of scientific activity but is not usually referred to in school science. It seems to me to be vital that students understand that the claim of “truth” based on reproducibility is both the strength and the weakness of scientific knowledge. It explains why, for example, science can offer no clear answers in relation to timber harvesting and the sustainability of our forests (one of the topics in the Year 10 curriculum at my school). The relevant scientific knowledge is important, but limited, and can be appealed to from both sides of the arguments. Similar uncertainty surrounds some medical knowledge that may be of vital personal concern to students at some time in their lives. Unless students have some insight into where the knowledge has come from (and perhaps how theory may guide—or blind) the danger is that they will unthinkingly accept scientific authority or abandon rationality altogether.

An Alternative Purpose in the Face of Practical Necessity

I was teaching a unit on introductory chemistry for Year 10 students. Although I had little expectation that experimental work would be an effective way for my students to learn theory, I nonetheless felt practical activity was important. This was partly just because
students enjoy laboratory activities, especially those that involve chemicals, Bunsen burners, and test tubes. I was also faced with a practical problem of my own, caused by the difficulties of adjusting for the timetable of careers lessons for the Year 10 students. For more than half a term, I was to lose half of the class (n = 30 students) for one out of five science lessons each 6-day cycle, and the other half for another lesson. I needed a way of making constructive use of the time with each half class by doing something that would minimize the inevitable loss in continuity.

I decided to teach the content of the unit, concerned with atoms, molecules, and chemical change, during the lessons when I had the whole class, without doing practical experimental work, although making use of demonstrations. I used the half class lessons for laboratory activities. I collected from various sources as many different chemistry experiments as I could find, placing photocopies into display books. Usually I rewrite any experiments I do, using more direct and accessible language, and making the instructions more complete and helpful, referring to the particular equipment that we have. This time, however, I did not do this. I asked the students, working in groups, to select an experiment they would like to do. They then constructed a flow chart, showing all the things they needed to do, and distinguished these from the things they needed to observe or decisions they needed to make. When they had assembled all the necessary equipment, they “walked through” the procedure for me, using the equipment but no chemicals. Once they had done that, they were then allowed to actually do the experiment. If they had time, they then repeated the whole process for a second experiment. Most of the experiments were fairly complicated, and many groups had to solve some minor problems before they achieved satisfactory results.

Each member of each group wrote a report for one of their experiments, describing the procedure they finally used, as well as the difficulties they had encountered and their results. The reports were then passed to a group who had not selected the same experiment, and this “verifying group” was asked to repeat the experiment using only the report written by the original group. This was an attempt to simulate the process of publishing an experiment in a scientific journal, and submitting the results to scrutiny and verification by the community of scientists. I hoped that it gave the students an audience and purpose for the written report, giving it a bit more meaning as an exercise in communication. The verifying group provided feedback to the original group who then rewrote their report before I assessed it.

Although my purposes in this exercise were not primarily for the students to learn chemistry content, I did nonetheless have some content-related goals. It seems to me that the concepts of chemistry are formal and abstract, to a degree that places them beyond the grasp of many Year 10 students, especially those in the class I was dealing with. This abstractness is exacerbated by the fact that the students have had few concrete experiences of chemical reactions to provide them with the basis for the formal understanding of the nature of chemical change. By structuring the experiments in this way I was able to expose the students to a variety of examples of chemical change, both directly through the experiments they performed, and indirectly through the other experiments going on around them. In this way they had some experience of a greater number of examples of chemical change than they might have had if I had selected a few experiments for the whole class to do. I also hoped that allowing a degree of choice in the experiments would lead to some ownership of the whole process.

I had originally hoped that the students would have a chance to reflect on what they had done, and what they had observed, and that they would be able to use what they were learning in the theory classes, to make sense of their experiments. Unfortunately the real world intervened: time ran out and the end of the term arrived.
Laboratory Work and Learning About the Nature of Science

The alternative purpose that Christina describes above is not, at least in the very broad sense of having students learn about “the nature of science,” new. Indeed the strongest advocate of laboratory work in the English speaking world before the First World War, H. E. Armstrong, centred this advocacy on discovery, experimental method, and the view that “the beginner not only may but must be put absolutely in the position of an original discoverer” (Jenkins, 1979, p. 44). In essence, his position was that just by doing science one learned about the nature of science, and that this learning should be a central feature of science education. This broad purpose for laboratory work declined in acceptance during the first half of the twentieth century, as did the use of laboratory work itself. The emergence of curriculum projects in the 1950s and 1960s, with their return to an emphasis on laboratory work and adoption of aims relating to the ways scientific knowledge, structures, and models were established, regenerated interest in student leaning about “the nature of science.” Instruments for assessing some forms of student understanding of the nature of science have been intermittent features of science education research since then, and intentions to teach about these issues have remained a common feature of curricula. For example, the more recent review by Lazarowitz and Tamir (1994) lists seven rationales for student laboratory work; four of these involve learning about issues linked with the nature of science such as how scientists work, problem solving, defining problems, scientific attitudes (p. 98). However, much of the relevant research conducted in the 1960s–1980s has focused on the evaluation of the effects of whole curricula, and not on the effects of specific laboratory experiences. In most of these cases the curriculum appears to be adopting the position of Armstrong—that by just doing laboratory work students will learn about the nature of science. The variable outcomes, in terms of student learning about the nature of science, that these studies report are therefore difficult to interpret. However, it is reasonable to conclude that this total curriculum approach, with learning about the nature of science as a form of implicit additional aim, is not helpful. This conclusion is reinforced by Tamir’s (1991, p. 16) brief comparison of who does what in typical school and research laboratories—little of what the student does is what the research scientist does.

In the last decade approaches to both the fostering of, and research on, student learning about the nature of science have changed. A significant contribution to this change, and certainly for our thinking, has been the paper by Millar and Driver (1987). For much of the twentieth century curriculum and research assumed, often implicitly and sometimes explicitly, that “content” and “process” in science were discrete. That is, the common assumption was that the concepts and structures of science, and the approaches that led to the acceptance of these concepts and structures, were separate and should be considered as such in curriculum and research. Millar and Driver show convincingly that this is not so, that “content” and “process” are intertwined and interdependent for the learner. With acceptance of this position research concerned with student learning about the nature of science and scientific inquiry has grown significantly in the last decade. It has also expanded in scope to include broader pictures of student views, such as their notions of theory–experiment links in their school science (Solomon, Scott, & Duveen, 1995). There has been a rebirth of interest in the views of pre-service and practicing teachers (e.g., Lederman, 1999), including studies of making explicit instructional intent relating to the nature of science (e.g., MacDonald, 1996) and descriptions of approaches to seeking to change student–teacher ideas about the nature of science (e.g. Hammrich, 1997).

The issue of particular significance for the present study that is a common conclusion for this research is that
Quite simply, the assumption that students are likely to learn the nature of science through implicit instruction (i.e. performance of scientific inquiry with no reflection on the nature of the activity) should be called into question. This is not meant to deny that many things can be learned implicitly (especially in the skills areas), but there is a difference in this case between doing something and understanding something. (Lederman, 1999, p. 928)

In terms of our use above of “purpose,” there is research support for the view that when teachers have learning about the nature of science as a purpose for laboratory work, then explicit student understanding of this purpose is important to student learning.

The Purpose of Laboratory Work: Students’ Perspectives

As a part of our research investigating students’ learning in the laboratory, we have interviewed secondary students about their perceptions of the purposes of laboratory work (Berry et al., 1999a, 1999b). Many of these students did not know why they did laboratory work. While a number did say that it helped their understanding of theory, further questioning revealed that most meant by this statement that it verified theory they had previously learned (which is partly a recognition of the aim of particular laboratory activities rather than the overall pedagogical purpose as we have described it), or gave them a “feel for or an image of” a particular phenomenon. And many who claimed this purpose for laboratory work could not give one specific example of a particular experiment that achieved this for them. Although there is some value in such outcomes, they do not point to much mental engagement during laboratory work. That is, we found little evidence of students reflecting on the value of their observations and trying to link them with what they already knew. This assertion of lack of mental engagement (as similarly highlighted by the conversation with a student reported by Rop, 1999, and recounted above) was borne out by our observations of students during a range of laboratory classes.

Why We Were Interested In Christina’s Work

Christina was conducting these activities at the same time that we were investigating the nature of students’ learning through laboratory work. The primary focus of our research was an investigation of the relationship between students’ science content knowledge and the ways in which students mentally engage with laboratory tasks. We had already conducted some preliminary research that had led us to identify a number of factors important in encouraging students’ mental engagement with, and learning from, laboratory tasks. These included the extent to which students know the content knowledge assumed by laboratory activities (students with little or none of the assumed content knowledge find it difficult to derive any meaning from the activity or their results), and the extent to which students are aware of the aim of a laboratory activity and the pedagogical purpose within their current science learning (students make better sense of what they are doing when they are aware of the aim and the purpose). Allied to this, we also identified the important role of the teacher in clearly articulating the purposes of a laboratory task and encouraging students to make links between their laboratory work and concurrent science class work. (For a more detailed description of the research and our findings see Berry, et al., 1999a, 1999b.)

The investigations that led to the findings reported above were all conducted in laboratory classes where the teacher’s main purpose was to improve students’ understanding of specific
science content. Christina’s work with her students gave us an opportunity to investigate the
effect on students’ learning from a laboratory task where content was not the teacher’s primary
consideration. If, as our research indicated, the extent of students’ laboratory-related content
knowledge was an important factor in determining how much students learnt from a laboratory
task, we were interested in exploring the effect on student learning in a laboratory task that was
not primarily concerned with content knowledge.

We also wanted to include Christina’s work as a part of our research because her
considerable experience as a teacher and researcher enabled her to articulate some ideas about
how practical work might reflect the nature of science knowledge. As we had already identified,
the role of the teacher (and her underlying pedagogical purpose) is most important in
communicating to students the reasons for undertaking a particular laboratory task because it is
related to what they learn from it. We wanted to learn how Christina’s intentions were
communicated to, and understood by, her students. In addition, she was embarking on a teaching
program driven by pedagogical purposes that would mean, in practice, that the students would be
taught through laboratory work in a “non-traditional manner” and would be involved in
cooperative group work: as Felder and Brent (1994, 1996) noted in their work (with a similar
purpose), communicating such learning experiences to others is important.

Management and Other Associated Classroom Issues

This activity was conceived in response to a practical problem, but it was by no means a
straightforward solution. The lessons were extremely hectic! I am not a chemist, and did not
know myself how some of the experiments were supposed to work. With every group doing
different experiments, the problem of anticipating what could go wrong was multiplied several
times. At some moments I felt the chaos bordered on irresponsibility. On one memorable
occasion, Pam (researcher) was observing. One group held a filter paper saturated with the
bleach they were experimenting on and, in accordance with their interpretation of the instruction
to ‘dry the paper,’ were shaking it vigorously, spraying drops of bleach everywhere. Pam was
cowering in a corner, imagining, I discovered later, the hazardous activities her daughter at
another school might be doing in science that day. However, two coincidences proved very
fortunate. One was that, at the time, Mandi (researcher and teacher) was also my colleague at
school, and offered to help out in some of my classes. During one lesson when I had the whole
class, the students were trying to get my attention to watch them walk through their procedure,
and it was logistically impossible for me to get around to every group. Mandi’s support was
invaluable at that stage.

Secondly, when the students were actually doing the experiments, I had a very competent
student-teacher ostensibly “observing” my classes. He made himself extremely useful,
troubleshooting by helping the students get started, and making sure some disasters did not
happen. I also had an exceptionally capable and patient laboratory technician, who was herself
a student and understood something of what real learning involved. She spent much time in the
classes, working with the students to solve the many practical difficulties that came between the
written instructions and a successful outcome, but allowing them to own the solutions.

My student-teacher also turned out to be a treasure in another way. I was thinking that, in an
ideal world of unlimited time, energy, and other resources (money!), it would be good to get a
young practicing scientist in to talk to the students about journals and conferences, and why
those things are part of scientific activity. My student-teacher turned out to have a Ph.D. in
physics, and in more congenial times would have been following his heart’s desire of being a
researcher, probably becoming a very good university teacher. While his work on electron
scattering was not obviously connected to experiments in chemistry, it was still scientific research. He needed little encouragement to share his passion with the students, and gave them an excellent “guest lecture” showing them journals and conference papers in which he had been involved.

Reviewing The Exercise: The Teacher’s Perspective

As a teacher it is often difficult to gauge whether the students have gained the learning you hope for from an exercise such as this (i.e., whether the pedagogical purposes were genuinely achieved). What was very apparent was that the students enjoyed these experiments, and one unexpected bonus was the positive effect of this exercise on my relationship with the class. They dealt wholeheartedly (in the same way Dewey, 1933, described wholeheartedness as both an attitude and a way of acting) with the problems they encountered, and even girls who had been lukewarm about science enjoyed bizarre challenges like collecting a gas under water, or producing a brown gas in a fume hood, or finding an indicator that gave an appropriate colour change. Hence, it is fair to assert that their laboratory experience became for them, genuine. This enjoyment factor seems especially important in a unit which is conceptually so demanding. It was also evident that having a clear reason for writing the reports greatly enhanced the quality of their descriptions of the experimental procedure. Being able to follow instructions, and write clear instructions for another person are useful general skills in which students sorely need practice.

The topic was well suited to this approach, as a good range of different experiments is readily available. In addition, with a few exceptions, experiments in chemistry are not well suited to student-designed investigations, which, in my experience, can provide worthwhile practical activity where they are appropriate. The age of the students was also suitable, as most Year 10 students (aged approximately 14–15 years) have sufficient responsibility and “nous” to deal with the challenges they faced.

However, the cost was considerable, as a huge amount of energy and organisation was required, not only by me, but also by my laboratory assistant. There were some unexpected problems, apart from the experiments that did not quite work in the way that the books suggested they should. The most significant problem arose when I returned the reports to the students who had written them, with feedback from the verifying group. A few students took the criticism personally, and the students who had provided the feedback expressed misgivings to me about the process. I was quite unprepared for this, but felt that the issue needed to be dealt with immediately. Before dismissing the class I spoke to them very seriously, and told them that I expected them to take the feedback in the spirit in which it was meant. I said that under no circumstances were they to discuss the feedback they had received outside the classroom. As far as I was aware there were no recriminations. As the student-teacher/research physicist, who was observing at the time, said to me afterwards, it does happen that scientists get hurt by the criticism they receive. If this issue ever arose again, I would certainly make that point to the students!

Method

Keeves (1998), in an extensive overview of ‘Methods and Processes in Research in Science Education’, and notes that, “There is no single method that is or should be employed in science education research.” (p. 1133) However, views about method inevitably influence the nature of research itself and the way that results are interpreted by different audiences. Therefore, Tobin
and Fraser’s (1998) reminder that, “different research studies call for a focus on different levels or ‘grain sizes’ which, in turn, have implications for the choice of research methods” (p. 627) is an important way of understanding the research approach adopted in this particular study.

Nakhleh (1994) incorporated “alternative approaches” (Vee-diagramming and concept maps) in her search for appropriate methodologies for investigating how learning occurred in the laboratory. With a similar intent of better probing understanding, in this study we too were developing ways of “seeing” the students’ learning as they worked their way through Christina’s laboratory activities. In this instance, we had one class of high school science students working on a laboratory approach that was new to them.

The students were in an all-girls’ Catholic College and were Year 10 students (age approximately 14–15 years) all of whom studied science as a core curriculum subject at that level. Within the class we were looking for different “grain sizes”—the examination of which might help to develop a richer picture of the situation. Through the use of one research tool (a survey described in detail below) we sought trends within the whole cohort of students while other research tools were designed to search for meaning through “intensive qualitative interpretive methods” (Tobin and Fraser, 1998, p. 627). In essence then, within the one study we were adopting methods to help us differentiate between “grain sizes” in ways that were appropriate for identifying the meanings that events had for those who participated in them and for those who witnessed them: students, researchers, and teacher alike (Erickson, 1998).

As the previous sections indicate, we were involved in a study that required monitoring and documenting students’ learning throughout this unit of work. But we also needed to develop ways of understanding why the students responded in the way they did (both in terms of their actions and their thoughts) as the unit unfolded before us. We therefore developed a methodology (discussed in the following section) that was responsive to the situation in order to account for the different data sources we considered would be helpful in explaining the situation. The data sources were:

- classroom observation, and field notes documenting these, throughout the unit of work (lessons over a 6-week period)
- paper and pencil class survey administered about half way through the unit—\(n=22\) (see Appendix A)
- copies of all student work (including laboratory “reports”) \(n=30\)
- individual student interviews at the completion of the unit focusing on students’ perceptions of the purpose of the task \(n=10\), randomly selected)
- laboratory group interviews post unit of work (see Appendix B)—(laboratory groups, \(n=4\) out of a possible 10 groups; approx. 3 students per group) audiotaped

As Christina had a clear purpose for her approach to this unit of work, we felt it was important to observe both the teacher and the students during the lessons for two reasons. The first and more obvious was to have a clear understanding of the way the unit developed. The second was to inform our decision—making about the issues and events to follow-up in interviews and discussions and to highlight any likely discrepancies among different perspectives (teacher, students, researchers) on issues and events. Throughout the classroom observations, the intent was to maintain a reliable descriptive record of events and to use these observations for debriefing with Christina and the research team. As the class was divided into two groupings (due to the movement of students out for one lesson a week for careers classes), observations covered both of the separate groupings during their laboratory activities as well as many of the lessons in which the class was together as a single unit, for example the visiting physicist’s talk and other important “linking” sessions.
Field notes were taken to develop an accurate record of particular episodes and student–
student negotiations (Olugbemiro and Taylor, 1995) for later analysis. For example, as the
students were working on their laboratory activities, discussions about how to proceed, what
might be important to do (or not do), how to determine appropriate forms of communication, and
general reactions and feelings about the work were recorded and formed a basis for informing
the research team’s views about how the unit was being interpreted by the students. Similarly, the
field notes were also important in shaping the nature of individual interviews and the focus of
group interviews in terms of both the questions and the students involved.

Half way through the unit, emerging data from the classroom observations suggested a need
to validate some of the conclusions we were tentatively drawing. It was therefore decided to
develop a brief open-ended survey to explore how the students had (to that point in the unit)
come to understand the nature of the work they were completing. At this time the students had
completed their first report to communicate their work to another group of students, and had
heard from the “visiting scientist” about the nature of experimental work in science. Students
had not yet passed their reports on to another group, and so the second phase of experiments
(attempting to replicate on the basis of a report from another group) had not yet begun. The
survey attempted to identify and quantify the responses to the situation and was intended to help
develop our understanding of the range of interpretations (and accompanying reasons) the
students had about the purposes of the unit of work. The survey was administered to all of the
students present at the time ($n = 22$) toward the end of a lesson.

The semi-structured student interviews that followed the administration of the survey were
designed to explore generally how the students had felt about the attempt to communicate their
laboratory work to others. As part of the teaching unit, the students were expected to write a
report that would communicate their work to others, then each group was to write a letter about
the effectiveness of the way the information was communicated, then return it with the report to
the original group. These interviews explored how the students were responding to that task and
the research team used the results to shape the nature of the focus group interviews which would
be conducted at the end of the unit. Those students interviewed were a random sample of
students ($n = 10$) from across all the student groups.

Laboratory group interviews (the same student groups as conducted the experiments) were
specifically selected as a mode of data collection so that members of the group could listen to,
and respond to, one another’s views. Laboratory groups also offered another opportunity to
explore another “grain size” as the survey offered individual’s thoughts, laboratory group
interviews offered groups’ thoughts. Laboratory group interviews were also important in terms
of the organization of a class of students and offered one way of obtaining a cross-section of
students without taking every student out of subsequent classes. The laboratory groups caused
the least confusion to the cooperating teacher and school. The laboratory groups therefore
consisted of a range of “available” students with each of groups 1–3 containing four students,
and group 4 containing two students.

Clearly, the methodology we adopted for this study in part developed in concert with the
unit of work. We were interested in understanding how the students’ understanding developed
throughout the unit and these different data collection procedures both informed our study and
adapted to the changing conditions within which we were all working. The use of different
instruments at different times throughout the study was a purposeful choice to track the way the
students were interpreting the unit and their learning and to better understand the reasons
underpinning their thoughts and actions. Hence, our method did not adopt pre- and post-test
instruments but rather was responsive to the situation in order to offer a richer picture of the
experience from the students’ perspective.
The way these data collection procedures led to an understanding of the students’ learning is illustrated in the following section as we explore the different “grain sizes” that required attention through this study. Data from the survey illustrate the range (and frequency) of responses offered by students, the data from the laboratory groups is indicative of students’ responses from the particular group and illustrates the nature of their thinking in relation to particular questions/prompts/issues. It is the shift in understanding that we are particularly attempting to highlight through these data.

Students’ Responses to the Experimental Activities

As noted above, we collected data from Christina’s classes using several different methods. One of the researchers observed Christina’s classes. Informal observational data were gathered while students were preparing for, and carrying out their initial experiments. The survey was intended to explore students’ views of the experimental work that they had been doing and whether they made any links between this and the student-teacher/physicist’s talk (see Appendix A). Their survey responses are outlined below.

**Students’ Survey Responses**

The data from the survey clearly supported Christina’s comment earlier that students enjoy experimental work involving chemicals, Bunsen burners, and test tubes (21 of 22 responded that they enjoyed these kinds of classes). The data also indicated the extent to which students recognized her purposes at this stage. In response to the question about the point of the experiments, students mentioned a range of purposes. These are summarised in Table 1.

<table>
<thead>
<tr>
<th>Response</th>
<th>Students Responding</th>
<th>Total</th>
<th>Responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry in everyday life/how things are made/see reactions</td>
<td>1,2,4,8,16,17,18,19,20,21</td>
<td>10</td>
<td>32</td>
</tr>
<tr>
<td>Design and follow a flow chart</td>
<td>5,9,10,11,12,13</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Experience doing a prac</td>
<td>1,2,12</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Learning aspects of experimental work (technique, equipment, how to write report)</td>
<td>2,22</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Learn about particles</td>
<td>6,18,20</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Prac work helps understand theory</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Reflection on experiment leads to an understanding of “why.”</td>
<td>5,14</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Communication of information to others</td>
<td>10</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Cooperating with others</td>
<td>9</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Be successful in experiments you don’t know anything about</td>
<td>7</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>See how scientists work</td>
<td>15</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

NB: There may be more than one possible response per student.
The most common response, from almost half the class (10 of 22), was that the experiments gave them the opportunity to observe some chemical reactions, one of the subsidiary purposes that Christina listed earlier. The second most common response (6 of 22) was to design and follow a flow chart, which is related to another of Christina’s purposes of developing skills that are useful for experimental work. The third most common response (4 of 22) had to do with being given experience in doing experimental work and how to use equipment and write a report which again is related to this purpose. Only one student gave a response that was connected to Christina’s primary purpose of giving students insight into aspects of the practice of science and how scientific knowledge is established.

That most students at this stage were not aware of this primary purpose is also reflected in their responses to the questions about the student-teacher/physicist’s talk. Few students appeared to make any links between the talk and their current science work. Most of the 20 who attended saw the most important message of the talk as being the breadth and nature of physics. Half the students (10 of 20) indicated they did not think there was any link between the talk and the experiments they were doing. Among those who saw a link, half (5 of 10) thought that this was because they were doing physics. Two students made written comments that indicated that they had some sense of the intended purpose of the talk:

- Just how people think up experiments.
- Just showing us that experiments and theory go under much scrutiny before the findings are considered fact.

**Students’ responses post report-writing**

At the end of the sequence of activities, when students had completed their investigations and had shared their work with other groups in the class, their written reports about their experiments were collected, including copies of the letters they had written to each other about their investigations. Audiotaped interviews with four separate laboratory groups of students (totalling 11 of 22) were also conducted to explore perceptions of the work they had completed in the unit. There were three students in Groups 1–3 and two in Group 4. These groups represented a range of ability levels.

During the interviews the students were asked what they believed to be the teacher’s purpose for the tasks given during the unit, whether there was anything unusual about these tasks, and what they had learned about doing experiments. The student responses showed interesting shifts in their thinking compared to when the survey was conducted.

Within each of Groups 1–3, students shared similar views (as noted below, Group 4 was an interesting exception). It was common during the interviews for the other students to murmur or openly express agreement when one of them spoke, and for students to complete each other’s sentences. For each group we summarize below their responses and given examples of student quotes that are representative of the comments made during the group interviews.

Groups 1–3 clearly linked what they had been doing with the way scientists work. Group 1 generally agreed that the purpose was to carry out and report on an experiment in such a way that another person reading the report would be able to achieve the same result following the procedure. As one student commented,

- That was the whole point—to make sure we got the same results.
This student thought the task of repeating someone else’s results “was a bit weird at first” but after the student—teacher/physicist’s talk “it made sense,” because she saw that what they were doing was, “what scientists do all the time to make sure that their results are accurate.”

Group 2 referred to the difference in purpose between the experiments in this unit and others they had done:

I think the [purpose] was different this time, it wasn’t just to . . . see the result of the prac [common Australian term for a laboratory activity], it was to experience something greater, [to experience] the role of the scientist.

Through acting out this role the group had come to understand the importance of accurately recording the results of a scientific experiment in order that others might repeat the result “so it could be proven as factual and right”. This group commented that they had not initially understood the purpose of the tasks because it was different from their previous experience:

In the past the things we’ve done . . . [were] mainly just to see what happened and to fill in time, not to actually get a result [that could be confirmed by others].

They thought the tasks were a valuable means of achieving an understanding of the way scientists work and how scientific knowledge is constructed:

It shows you just how clear everything has to be and how sometimes tedious it is . . . if you’ve discovered something, how thorough you have to be when you’re rewriting it.

Group 3 valued the way the tasks were constructed so that each group was successful:

. . . we got things right, no-one was wrong because . . . we went through so many different procedures—like doing the experiment, rewriting it, giving it to someone else . . . so we all had a part of it, we all got something right.

As with Group 1 the student-teacher/physicist’s talk was an important factor in helping them achieve a sense of purpose:

He sort of told us that what we were doing . . . that was what scientists do . . . it made me . . . confident in what I was doing.

In addition to their shared sense of purpose about their experimental work, Group 1–3 also made similar remarks about the value of learning by doing. They felt that they had derived a better understanding of scientists’ work through the tasks given in the unit than they would have by merely reading or being told about it.

To be actually acting [the role of the scientist] out . . . It’s a better way of learning I think rather than just sitting down in class writing and taking down notes . . . I think it was better to be actually doing it because you can understand . . .

The responses from Group 4 were quite different to those of the other three. Unlike the other groups, these (two) students did not refer to a connection between the way scientists work and the tasks they had been given. Both students had perceptions about the purposes of their experimental work which were quite different from those intended by Christina and which were related to personal concerns.
Student A said the purpose of doing the experiments was to observe some chemical reactions and to “write up the reports so you get the same results as what the other group did.” This student, who was new to the school, interpreted the tasks they were given as a model for how experimental work should be done in her new school:

A: I’m new this year and I learned how they worked with their practical work and how they wrote up pracs and stuff because I did it a lot different at my other school.

Student A did not see any link between the student-teacher/physicist’s talk and the experimental work they had done. She saw the talk as being an extension of things she had already learned in physics at her previous school:

A: It was quite . . . similar [to] what I knew already . . . last year I did physics . . . it was like an extension to what I knew [about physics].

Interviewer: Did it have anything to do with prac work?

A: Not that I know of.

The other student in this group (Student B) who had always struggled with science, say the tasks as providing her with a useful structure for doing experiments:

B: I think it was very different to what I had [in Year 9] . . . It’s more structured . . . has a step-by-step way of doing it which I think is good because it’s like guidelines to help you to do it.

Clearly both the Group 4 students saw purposes for the unit which addressed their personal needs which in fact were not related to those intended by Christina.

Affect

Christina mentioned that the students enjoyed the hands-on nature of the tasks. It was also clear from the interviews that the students valued the cooperative nature of the activities and learning to work with each other.

Interviewer: Have you learned anything else about prac?

S1: To cooperate with each other.

S2: [We got to know each other better] and then we work harder.

S3: . . . I think that with working together as a group we all helped each other and that was the best thing [about it].

That the students valued the importance of getting on with each other and this was also shown in the letters the “verifying groups” wrote as feedback to the groups who had originally performed the experiment. Most letters were written in such a way that one of the researchers was led to ask, “Was there a proforma?”1 for they followed a pattern of saying something “nice,” then criticising as appropriate and ending with another “nice” comment. (There was no proforma or other guide to structure and style for the letters.) It also needs to be noted that “real” cooperation was required to solve the technical problems. Most laboratory work requires students

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1 A proforma is a standard layout for a document, in this case suggesting that there was a specified approach to respond to one another’s work.
to work in groups, but the cooperative demands here were greater than that which is usually the case in practical work.

As these students were all aged around 15 years, and at a stage of their development where social interaction with peers is seen as being of paramount importance, it is not surprising that they enjoyed the cooperative nature of the tasks. However, it is not clear to what extent this impacted on their learning in the cognitive domain.

**Summary**

Groups 1–3 saw the teacher’s purpose behind the tasks they had undertaken as being to develop an understanding of how scientists work and scientific ‘facts’ (their common description for science knowledge) are established. This was Christina’s primary purpose for the unit. While at the time of the survey it appears that the students were not making links between their activities and the talk, the interview responses suggest that by the end of the unit they were making such links. This sense of purpose emerged as the unit progressed, with the student-teacher/physicist’s talk playing an important part. Many students said that acting out the role of the scientist helped them derive a better understanding than merely reading or talking about it. Hence it could well be argued that in the implementation of this unit of work the pedagogic purpose underpinning the approach had created an episode (White, 1988) for these particular students from which their understanding developed and was enhanced when they began to link the various activities. They may therefore have come to recognize the intent as a whole rather than as discrete units—which is a more commonly reported outcome of school learning.

Group 4’s perception of the purpose did not correspond to Christina’s. This is understandable in the light of their immediate concerns which, for one student, had to do with how to fit in to her new school and, for the other, how to deal with a subject which she had always found difficult.

In addition to achieving Christina’s purposes the students also derived a sense of satisfaction from the cooperative nature of the tasks in the unit.

**The Teacher’s Learning**

As I have already noted, I was aware that the exercise had been successful, in the sense that the students clearly enjoyed it. It was, nonetheless, very affirming for that to be confirmed in the feedback that the researchers obtained. However, without the presence of the researchers I would probably never have known whether my students learnt anything significant about science itself. I was, in fact, rather surprised that they did understand my intentions [purposes] as clearly as they apparently did. I did not feel I had communicated the reasons for what I was doing any more effectively that I communicate my reasons for doing anything, and I know I am not usually so well understood!

**Conclusion And Implications**

Our interest in the question posed in the title of this paper—“What is the purpose of this experiment?”—developed from our earlier research which showed that many students did not know the purposes behind their laboratory investigations. We concluded that while teachers often emphasize the scientific aim of a laboratory task, it is equally important that students are aware of its purpose if worthwhile learning is to be achieved. In addition, while much laboratory work has a common purpose of seeking to develop students’ understanding of science content
knowledge, we had found that students also need to have sufficient relevant content knowledge prior to the activity if they are to meaningfully engage with it. It is clear to us then that teachers need to make the pedagogical purpose of laboratory work explicit for students. In so doing it might better help them to make the links between tasks in such a way as to build a more holistic view of their science learning experiences.

The significance of the laboratory work reported in this paper lies in its very different purpose (to give students some insight into the ways scientific knowledge is established), the strong and logical links between this purpose and the detail of the activities, the consequent relative lack of importance of prior chemistry content knowledge (students had to know enough to be able to do the experiments but did not have to explain their results) and its success in terms of intended student learning. As our research showed, the students made strong links between the teacher’s intentions and the tasks they were given. As this linking occurred gradually, it seems that it was the set of experiences that comprised the unit as a whole that had an impact on students’ thinking about the practice of science. It is also clearly consistent with the data to argue that student knowledge of the purpose of the unit was of real significance to the student learning that was evident by the end of the unit. We believe that the major issue in this student knowledge of purpose was the limiting of the teacher’s intentions to the learning of some specific aspects of the nature of science (the roles of communication and replication in the acceptance of new knowledge), and the careful designing of experiences that directly related to these intentions.

It is reasonable to suggest that the strong presence of the researchers in the classroom would have impacted on students’ learning from this task. We have been following Christina’s year 10 science class in the year subsequent to the collection of the data reported here, in which a similar task has been carried out, this time in ways that do not explicitly involve the researchers. It would appear from our preliminary findings that the students in this later year have also developed a clear sense of the teacher’s intended purposes.

The subtitle of this paper was “Can students learn something from doing experiments?” The answer is clearly “yes.” While research has generally shown that laboratory work is not always a useful strategy for teaching science knowledge, this investigation has shown that it can be successfully used for other purposes. In this case it was used to help students to think about one aspect of science (developing, communicating, and verifying procedures and results from laboratory work). It is interesting to ponder whether this purpose would have been achieved if there had been an expectation that students would engage with the results of their experiments, or try to explain them, as is usually the case. Furthermore, Christina’s primary purpose, of providing students with an insight into one aspect of the way science is conducted, was deliberately constrained. She focused on the importance of communication, publication, and verification of results. The limiting of purposes by the teacher was crucial to the success she did achieve. Perhaps here lies a clue to the failure of laboratory work in terms of student learning: by claiming too much for laboratory work, we diminish what we can achieve.

Appendix A: Open-Ended Survey Given Half Way Through the Unit

1. What is the point of the experiments you have been doing in your prac classes lately?
2a. Have you enjoyed these kinds of Science classes?
2b. How does this experimental work compare with other kinds of Science work you’ve done this year?
3. When you write up your own report from your experiments, what are the most important things that you will need to write in order that your experiment can be repeated?
4. Think about the talk that the visiting physicist gave on Monday.
   (a) In the way you understood it, what do you think were the most important messages of the talk?
   (b) What do you think the physicist’s talk has to do with the experiments you’re doing?

Appendix B: Protocol for Post-Unit of Work Interview about Prac Work

Think about what you have been doing in Science over the last few weeks—preparing for, doing, and writing about a prac, and redoing and commenting on someone-else’s prac.2

1. What was the teacher’s purpose for giving you these tasks?
2. Did you think there was anything unusual about the tasks you were given? (If yes) Why is that unusual? What is usual? (If necessary) Was there anything unusual about:
   (a) the teacher’s approach? (If yes) Why is that unusual? etc
   (b) how you prepared for the tasks? (If yes) Why is that unusual? etc
   (c) what you did with what you found out? (If yes) Why is that unusual? etc
3. Have you learned anything about prac work? (If yes) How did you come to learn that?

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References


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2“prac”, an abbreviation for “practical work”, is common Australian student vernacular for “laboratory work.”

