Chapter 2
Science Laboratory Learning Environment, and Learning

2.1 Science Laboratory and Learning

Internationally, practical work in a laboratory setting is considered to be a preferred learning environment for school science. Millar (2010) argues that if science education aims for students to understand the natural world and how it functions, then learners need to experience and observe the relevant science phenomena. Millar argues that through observation and manipulation of objects students are more likely to make the links between the domains of objects and ideas. Other science education researchers have argued that many benefits accrue from engaging students in laboratory activities in science (Dkeidek et al. 2012; Hofstein 2004; Hofstein et al. 2008; Woolnough 1991). Dkeidek et al. (2012) consider science laboratories provide an ideal environment for students to work cooperatively and investigate scientific phenomena. Assertions are made about the benefits of laboratory work, including fostering positive attitudes and interest in science (Hoffstein and Lunetta 1982; Luketic and Dolan 2013). Hodson (1990) suggests that the main reasons given by teachers in support of practical work include: motivational benefits (interest and enjoyment); development of skills and science knowledge; learning about and following scientific method; and developing scientific attitudes. However, there is considerable doubt about the effectiveness of laboratory work in school science (Abrahams and Millar 2008). In the literature, practical work and laboratory work are used interchangeably, although Millar (2010) argues that practical work can also take place outside the laboratory. However, in most high schools it usually occurs in the laboratory.

Osborne (1998) argues that laboratory work has a limited role and little educational value in science learning. Hodson (1991) asserts: "despite its often massive share of curriculum time, laboratory work often provides little of real educational value. As practiced in many countries, it is ill-conceived, confused and unproductive". Hodson goes on to say, "For many children, what goes on in the laboratory

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contributes little to their learning of science or to their learning about science and its methods" (p. 176). Abrahams (2009) has challenged the claim that laboratory work is motivational. In recent times, the attention has turned to finding out what students say about their learning.

Toplis (2012) investigated students' views about teaching and learning through practical work in the science laboratory. When given the voice in Toplis's study, students said laboratory work was important for interest and activity, and it gave them autonomy and an opportunity to participate. Students did not like transmission of knowledge from the teacher, rote learning and recall of facts. Rudduck and McIntyre (2007), in their research, found that students described good lessons for learning when: there was a lack of tedium; learning was meaningful; they were able to work together; and they had autonomy. It appears that when students have a choice, the learning environment that gives them autonomy and freedom to draw upon the ideas of their peers along with engaging in interesting tasks, they learn science.

2.2 Science Laboratory Environment Inventory

The SLEI was developed and validated by Fraser et al. (1995). This instrument is especially suited to assessing the environment of science classes because of the importance of laboratory settings in science education. The inventory comprises 35 items, each of which is judged on a scale of 1–5. This SLEI has an actual and a preferred version of the learning environment. In the actual version the students respond to the questions by selecting options that indicate how things happen in their laboratory class. In the preferred version they choose responses that indicate what they wished the classroom environment to be. The inventory has five scales: student cohesiveness, open-endedness; integration; rule clarity; and material environment. The SLEI was field tested and validated with 5,447 students from 269 classes in seven countries, including Australia. Fraser et al. (1995) used individual students as a unit of analysis and reported the internal consistency (alpha reliability) and discriminant validity (mean correlation of a scale with the other four scales). The statistics are reported in Table 2.1.

In the alpha reliability data, the numbers in the left-hand columns, are all relatively high; they show how the items in each set are internally correlated (e.g., all those items that measure actual student cohesiveness are quite highly (0.80) interrelated). The numbers in the right hand-columns are all relatively low; they show that the sets themselves are not highly correlated, for example, actual student cohesiveness has a low average correlation (0.31) with all the other scales. The description of each scale and an illustrative sample item are presented in Table 2.2 which is from Hofstein (2004, p. 355).

The SLEI has been used globally. Fraser and McRobbie (1995) investigated students' perceptions of their science learning environment in six countries including; UK, Nigeria, Australia, Israel, USA, and Canada. Hofstein et al. (2001) used the SLEI to compare the learning environments for students who engaged in an inquiry approach with a control group. They reported that the inquiry group found

Table 2.1 Internal consistency (Cronbach alpha reliability) and discriminant validity (mean correlation with other scales) for actual and preferred versions for a cross-validation sample for class mean as a unit of analysis

Scale	Alpha reliability		Mean correlation with other scales	
	Actual	Preferred	Actual	Preferred
Student cohesiveness	0.80	0.82	0.31	0.31
Open-endedness	0.80	0.70	0.25	0.15
Integration	0.91	0.92	0.44	0.36
Rule clarity	0.76	0.80	0.43	0.35
Material environment	0.74	0.85	0.34	0.40

Note Table from Fraser et al. (1995, p. 15)

Table 2.2 Descriptive information and sample items for each scale of SLEI

Scale name	Description	Sample item
Student cohesiveness	Extent to which students know, help and are supportive of one another	Members of this laboratory class help one another
Open-endedness	Extent to which the laboratory activities emphasise an open-ended, divergent approach to experimentation	In our laboratory sessions, different students do different experiments
Integration	Extent to which the laboratory activities are integrated with non-laboratory and theory classes	We use the theory from our regular class sessions during laboratory activities
Rule clarity	Extent to which behaviour in the laboratory is guided by formal rules	There is a recognised way of doing things safely in this laboratory
Material environment	Extent to which the laboratory equipment and materials are adequate	The laboratory has enough room for individual or group work

the actual learning environment more aligned with their preferred environment than the control group. More recently, Dkeidek et al. (2012) used a SLEI (translated in Arabic and validated) to compare the effect of culture on Jewish and Arab students' perceptions of their learning environments. Dkeidek et al. (2012) found that the responses were different in the pre-inquiry phase and similar in the categories that were measured during the inquiry phase.

2.3 Methodology

Although this SLEI was not tested in New Zealand, it was considered appropriate because the instrument was using items that were relevant to science learning in New Zealand laboratories. Both actual and preferred versions of the SLEI were administered. Students took approximately 25 min to complete the actual version and about 20 min for the preferred version. The students selected from five scoring options ranging from 1 (low) to 5 (high). The negative items were reversed before adding the responses for the five scales (see Table 2.1). A paired sample t test was applied for both actual and preferred items on each of the scales (see Table 2.3). The five scales used were open-endedness (items 2, 7, 12, 17, 22, 27, 32), material environment (items 5, 10, 15, 20, 25, 30, 35), integration (items 3, 8, 13, 18, 23, 28, 33), rule clarity (items 4, 9, 14, 19, 24, 29, 34), and cohesiveness (items 1, 6, 11, 16, 21, 26, 31). Open-endedness items relate to student control over the design and implementation of practical work, and the choice they had or would like to have had in investigating what they wanted to investigate. Material environment items were related to the physical aspects such as whether they had the equipment available to do the practical work and if it was in good repair. Integration items were about the relationship between the concepts they had learnt and the practical work they were doing. Rule clarity was about the parameters within which they had to work, for example how they understood the safety requirement. A cohesiveness scale was related to the human dimension of working together, helping each other.

2.4 Results

In this research, classroom observations were made for one lesson each week for an academic year. It is in these lessons that students carried out investigations. Students sat in groups of three and worked in these groups when doing practical work. The science investigations they participated in were mostly tasks set out in the laboratory workbook or were teacher directed. The teachers tried to get to the class a few minutes before the lesson and organised the materials required for the lesson. This is described in detail in Chap. 3.

2.4.1 The Science Laboratory

The science teacher, John (pseudonym), took his class in a laboratory where his colleague Stella (pseudonym) taught all her classes. John's classes came to this laboratory four times each week. Stella kept the laboratory tidy and had her students' work displayed around the room. Also displayed were a periodic table, the school's code of conduct, charts that indicated what students needed to do to be able to gain an achieved, merit or excellence grade in the examination. The room was well lit and had seating for 30 students and ten workstations along the side benches. According to field notes about the physical laboratory environment:

> The laboratory has basic glassware neatly organised in trays and commonly used chemicals; acids, alkalis, iodine, indicators etc. in sets of ten stored on the shelf. All the work displayed on the walls is from Stella's junior science classes. No work on the walls is from students in the study class. When the students arrive, the class is clean and tidy but they often leave it in a mess with bits of paper on the floor and other rubbish in the sink. (Classroom observation)

2.4.2 Results of the SLEI

The results of the actual and preferred data from the SLEI are presented in Tables 2.3 and 2.4. Results show a just significant ($p < 0.5$) difference between the actual and preferred option for open-endedness. The open-endedness scale is particularly relevant as it measured student preference for the science investigation they carried out. The actual score (3.14) was higher than the preferred score (2.98), which indicated that they did not want the laboratory environment to be more open-ended. It can be concluded that they wanted less choice in deciding what to investigate and more teacher direction. Classroom observations during twenty lessons showed that the pattern was for the teacher to "tell" the class what investigation they were going to do. Students in the study class became comfortable with having less choice and more teacher direction which is reflected in the results (See Chap. 3).

The material environment actual score (2.81) was significantly lower ($p < 0.001$) than the preferred score (3.62) and is indicative of their preference for more equipment that worked, a less crowded laboratory, and a comfortable and attractive place to work. The science lessons for this class were held in a laboratory where the students came for only their science lessons. Their teacher was not in-charge of this laboratory. The work displayed on the walls was not their work and there was a lack of a sense of belongingness in a laboratory that felt cramped and that had with equipment that did not always work which is reflected in the results for the material environment.

Table 2.3 Paired sample statistical results for science laboratory environment inventory

Environmental factors	Mean	Standard deviation
Pair 1 Open-endedness (Actual)	3.14	0.24
Open-endedness (Preferred)	2.98	0.21
Pair 2 Material environment (Actual)	2.81	0.42
Material environment (Preferred)	3.62	0.70
Pair 3 Integration (Actual)	3.35	0.65
Integration (Preferred)	3.83	0.76
Pair 4 Rule clarity (Actual)	3.37	0.40
Rule clarity (Preferred)	3.40	0.77
Pair 5 Student cohesiveness (Actual)	2.70	0.91
Student cohesiveness (Preferred)	3.88	1.18

Table 2.4 Results of paired sample t test

Environmental factors	t	df	Sig. (2-tailed)
Pair 1 Open-endedness (Actual)—(Preferred)	2.395	16	0.03
Pair 2 Material environment (Actual)—Preferred)	−4.573	17	0.00
Pair 3 Integration (Actual)—(Preferred)	−1.969	20	0.06
Pair 4 Rule clarity (Actual)—(Preferred)	−0.160	19	0.86
Pair 5 Student cohesiveness (Actual)—(Preferred)	−4.308	21	0.00

On the cohesiveness scale, the environment was significantly ($p < 0.001$) less cohesive (2.70) than students would have preferred (3.88), indicating that they would have liked to get along with each other and preferred to be able to help each other. Although students sometimes worked in groups, this was mostly because there were ten sets of equipment and the corresponding number of workstations. Students were not required to work collaboratively to plan and carry out their investigations or to support each other's learning.

Rule clarity was high (3.37) and this was preferred (3.40), demonstrating students had, or wanted to have, a clear understanding of the classroom rules and guidelines. Integration was seen to be high (3.35) and it was preferred (3.83), indicative of the close relationship between theory and practical integration in their class. The teaching approach was to teach the science concepts first and for students to then carry out practical work to confirm the theory.

2.5 Student Experiences of Learning to Investigate

During the year students carried out a number of science investigations (Table 2.5). In the first half year, most of these investigations took two to three 50 min lessons. The first lesson was for planning and the following lesson for gathering data. It was observed that when students were gathering the data, often no time was left to find out what they had learnt. Students left the class with the instruction to complete writing the investigation for homework but inspection of their books showed that very few students did.

Table 2.5 Science investigations carried out by the study class

1	Investigating metals *Effect of acids on metals*	8	Watch that car go *Effect of slope on distance travelled*
2	Separating mixtures *Decantation, filtration, evaporation, distillation*	9	Dry ice exploration *Physical and chemical properties*
3	Energy exploration *Energy transformations*	10	Fractional distillation *Teacher demonstration of fractional distillation*
4	Body power *Work, energy and power to climb up the staircase*	11	Energy released by fuels *Burning fuels and comparing energy released*
5	Rolling marbles *Distance travelled on different surfaces*	12	DNA extraction *Extracting Cauliflower DNA*
6	Heat retention *Heat retention in paper, metal and paper cups*	13	Electrical circuits *Building simple circuits and measuring current*
7	Culturing micro-organisms *Growing bacteria and fungi on agar plates*	14	Astronomy models *Models to investigate day and night, and seasons*

The data reported here are from student responses to a questionnaire about learning and focus group interviews with five/six students three times during the year. As the researcher was accepted as a member of the class, students often came and sat down and talked to her. These informal classroom conversations were insightful in providing rich data from the willing participants. It is noteworthy that the examples cited in this book are not cherry-picked but illustrative examples contributions that illuminated something important said by the students. The first example below highlights the importance of variety in the lesson and of the student belief that it is easier to understand something when they see it work. It was also used by the teacher to confirm the theory they had been learning about energy.

2.5.1 Illustrative Example 1

2.5.1.1 Selected Practical Activity: Exploring Energy Changes

The teacher arrived early and set up in the laboratory 11 stations with different activities of energy transformation and put instructions at each station for students to follow. Students were to do the 11 activities that were set out and record their observations in a table in their workbook. They also had to identify the energy change that took place at each station. The stations included a steady stream of water to turn a wheel, solar panels to convert light energy into electrical energy, a mouse trap to move a toy vehicle, and the use of wind from a hair dryer to move a ball, to name a few.

The students listened to the instructions and chatted at the start of the lesson but once they started on the task they moved from one station/activity to the next. Of the eight groups (three students in each), seven groups were engaged and on task throughout the lesson. These 21 students appeared interested, talked to each other and asked questions. In the last quarter of the lesson the teacher asked them to share their observations and conclusions with other members of their group. The eighth group had four students—Harry, Henry, Ken, and Jake—who did not have their books. Two of them made an effort to get a photocopied sheet from the teacher but did not do any activity. For the other students, the on-task chatter and the manner in which the students carried out the tasks demonstrated that they were interested in the activities. The following information about learning is from an audio-taped conversation with students while the researcher moved around the laboratory. When students were asked about their work they said:

Pip: This is fun. I got to do the practical myself.

Jessica: It is fun because we did not have to do just one thing for the whole hour. There were lots of different things we could do.

Bob: Yeah there was variety.

Simon: I can remember the science …. (the teacher) tells us when I can see it work before my eyes.

Ed: We did not have to do heaps of writing, that's so boring. (Transcript for observed lesson)

Of the nine students asked, there were seven who were able to identify energy changes accurately. For example:

Researcher: What is this activity about?
Bob: The solar cells change light energy into electrical energy.
Researcher: What have you learnt from doing these activities?
Mili: I have learnt all sorts of energy changes like a mouse trap can change elastic potential energy into kinetic and sound.
Jessica: Light bulbs change electrical energy into light and heat and heaters change electrical energy into mostly heat but some light. (Transcript for observed lesson)

Two students who were not engaged were asked why they had not done the activity, and what they had learnt. One said "not much really", while the other, Ed, said:

Ed: Because I already know the answers.
Researcher: Can you tell me what energy changes are taking place when water is dropped on the wheel?
Ed: Gravitational potential energy into kinetic energy, just like in the hydro dams. This is dumb, we did it in year 9. (Transcript for observed lesson)

An interesting aspect was that during a focus group interview nearly six months later, students talked about the investigations they had done during the year, and all remembered energy exploration investigation as one they had enjoyed the most, and were able to say what they had learnt from it. Focus group students were able to demonstrate their understanding of the energy changes. For example:

Pip: When we are using the power pack the energy change is mostly from electrical potential to light and heat. But when we use batteries it is from chemical potential to light and heat.
Ben: And we could say that it is from chemical potential to kinetic and then to light and heat if we consider that electrons are moving.

Similarly, there was discussion about what happens when a tuning fork is hit on a mallet.

Jake: …kinetic is changing to sound, but we used the chemical potential energy stored in our cells to hit the tuning fork on the mallet. So it would be right to say chemical potential changed to kinetic which changed to light and heat.

However, the same group of students did not demonstrate an understanding of the nature of science investigation, even though they had done several fair testing type of investigation. When asked:

Researcher: Why are you taking the readings ten times?
Mili: It makes our results more valid and reliable.

Upon probing about what Mili meant about ‘valid and reliable’, it became apparent that none of the students understood what reliability was; it appeared to be a rote learnt answer. The point had been stressed by the teacher several times during the observed lessons as something they needed to *write* to get a better grade in the assessment.

Students completed a questionnaire about their science learning in the first school term. The question focused on their views about learning science ideas through investigating. Eighteen out of 22 students responded to this question. One student said they found it very helpful, eight found it mostly helpful, nine said it was somewhat helpful, five did not find it helpful, and four did not respond. Their responses showed that most students found this investigation helpful to some degree in their learning of science. Eight of the 18 students provided comments. They indicated that it helped them to understand the formulae they needed and how to write an equation. Others provided general comments such as: helped me to learn; made it easy because when they got to “do” the investigation it helped them to remember; and “because it lets me see the concept rather than having to ‘see’ it in my head” (Respondent 8); and because investigation “proves the ideas and actually show them” (Respondent 13). All five of the students who indicated investigation was unhelpful gave comments which included: “it was stupid, if a ramp is steep something will go faster” (Respondent 17); “the class mucks around” (2); “they learnt more out of the book” (1); and “I already knew this from year 9” (Respondent 3).

2.5.2 Illustrative Example 2

2.5.2.1 Heat Retention in Cups of Different Materials

This investigation was selected to study in depth because it was the investigation to prepare the students for the final assessment. The teacher wanted to familiarise students with the process they would have to follow. It took three lessons just as the assessment would. In the first lesson, students planned their investigation, in the next lesson, they carried out the investigation and collected data, and on the following day, in the third lesson, they wrote their report.

The task in the first of three lessons was to design a fair test on the insulating properties of different materials as described in the workbook (Abbott et al. 2005). In this lesson, the teacher wanted students to understand the language used in assessment tasks by asking the following questions:

What is the dependent variable here?
What is the independent variable?
Which ones would you need to control?

> Between four and five groups engaged with the investigation they were to do. The rest talked, wandered, and were not engaged. At no time during this lesson were all students on task. Ed moved to sit next to me. (Observation notes)

Researcher: Where is your plan?

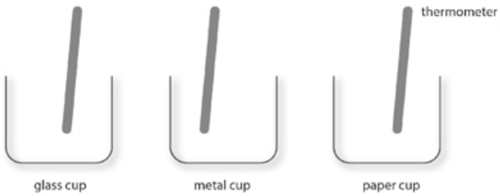
Ed points to a drawing in his book.

Researcher: What are these containers?

Ed labels them.

Researcher points to the stick in each container, what is this?

Ed: Thermometers, labels them.

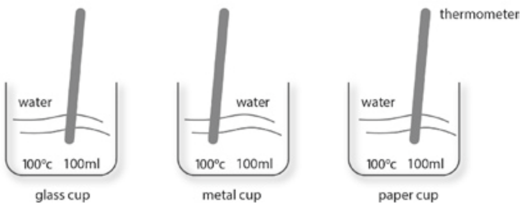


Researcher: What is in the containers?

Ed: Water.

Researcher: What else can you tell me about the water?

Ed: There is 100ml at 100°C in each container, and he labelled his diagram.



Researcher: Where will you record the temperature?

Ed: In a table.

He drew an appropriate table.

Researcher: Ed, you could have written down a complete plan and started the investigation.

Ed: Miss why would I want to do that? We did this last year and I already know the answer.

Fig. 2.1 Ed's plan for the investigation

The vignette in Fig. 2.1 is the conversation that the researcher had with Ed.

The message was clear, you learn something you did not know. Other students in the class were chatty and only a few got on with the task. Mili had collected all her data.

Researcher: What did you learn from this investigation?
Mili: That metal is the best, the tin.
Researcher: Is the best what?
Mili: It's an insulator.
Researcher: What else did you learn?
Mili: That the water cools fastest in the metal cup.

Evidently, Mili did not understand that if metal was an insulator the water would take longer to cool down. Later, this investigation was discussed in the focus group when several students gave their reasons for not engaging.

According to the focus group students, they already knew the science concepts because they had learnt them before. Their responses indicated that they had not considered that this investigation was to prepare them for their final assessment. The teacher's purpose for doing this investigation was to give students an opportunity to practise an investigation and learn the necessary terminology to become familiar with the process that they would need to follow in the assessment.

When students in the focus group were asked how this investigation helped them to prepare for the final assessment, the following discussion took place.

Bob: It showed us the lines which we had to follow to write out the method. How to use our time?

His response helped the others to remember doing this investigation:

Pip: And what we were looking for when we were doing it.
Researcher: Do you remember your teacher marked and returned your plan? Did anyone use that feedback that the teacher gave you?
Bob: No.
Researcher: Why?
Jake answered instead: I tried to, but I didn't improve my mark, but I'm still happy because I passed. (Focus group interview)

Through this investigation the teacher supported students' learning by giving them time to think what they had to do for their assessment. What the teacher did not know was that these students had already done this investigation the previous year.

2.6 Chapter Summary

The laboratory holds an important place in secondary schools, and classroom observations showed that most students, most of the time, were involved in "doing" practical work. In almost all cases, the investigation they were to do was either set out in the workbook or students were told what they were going to do. It is not surprising that students did not want open-ended investigations as it was easier to do what "they were told" and it then became a habit. This is contrary to Rudduck and McIntyre's (2007) research where students wanted autonomy and control over their learning. As can be expected, students wanted to have equipment easily available and in working order. Sometimes not having all the equipment was frustrating for them. They said that they wanted to work with their peers, and at times they worked in groups. However, the students wanted to sit with their friends but this was discouraged by the teacher who believed that it would lead to off-task behaviour. The common pedagogical approach was to teach the science ideas first and then to do the practical work to confirm what they had learnt in the theory lesson. This was problematic in that students were developing the thinking that by following a set of steps sequentially, they could get to the "correct" answer in order to achieve a better grade.

Ahmad et al. (2013) found a predictive relationship between teachers' perception of the learning environment and the satisfaction they experienced in their teaching. The results of the SLEI were useful as they provided the teacher with insight into students' perceptions about their current laboratory environment and how they would prefer it to be. Luketic and Dolan (2013) argue that teachers can respond to the SLEI results and make appropriate changes to make the laboratory environment conducive to student learning. These results were shared with the teacher who had the option to take the findings on board and consider how he could modify his pedagogical approach to address the learning needs of his students.

It is noteworthy that students enjoyed, and appeared to have learnt most from, exploration of a series of short practical activities set up as work stations. They explained their enjoyment in terms of the variety offered as opposed to doing one investigation for the whole hour. Another reason offered for enjoyment was doing the activity and not having to write too much about it. It was interesting that students in the focus group collectively could remember a number of investigations that they had carried out and what they had learnt from them. However, they did not appear to distinguish between 'investigations', whether it be fair testing or another type, and other practical work.

From the teacher's perspective, it was important to give the students an opportunity to learn the process they would need to follow for the final assessment, but this had not been communicated to the students. The teacher did not know that the students had in the past done the heat investigation. So, for those who understood the teacher's intention for learning, learnt from it. For those who thought it was about the science ideas that were to emerge from doing it, perceiving that they already knew them, there was no learning. It was indeed important for the teacher and the students to find out what they had learnt, but no time remained in the lesson for reflection.

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