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High School Laboratory Work in Western Australia: Openness to Inquiry

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Abstract

Laboratory work has always been the most distinctive feature of secondary science teaching and learning. With the increasing emphasis on student centred learning and the importance of developing investigation and problem-solving skills there is value in reflecting on the type of laboratory work that is carried out in the science curriculum. The purpose of this study was to determine the nature of the laboratory work undertaken by lower secondary science students, and in particular, to determine the openness to inquiry of these activities. The study also examined the factors that influence teachers in determining the type of student investigations that occur in the science laboratory. Data from a survey of Perth lower secondary science teachers reveal low levels of inquiry and interesting insights into teachers' perceptions about the benefits of open inquiry for students and the difficulties for teachers. The difficulties identified by teachers represent barriers to change that must be addressed if more open inquiry laboratory work is to be implemented in schools.

Garnett, Garnett and Hackling (1995) have suggested that the aims of laboratory work can be grouped into four main categories: conceptual learning; techniques and manipulative skills; investigation and problem solving skills; and affective outcomes. The Mayer Report (Mayer, 1992), the National Statement on Science for Australian Schools (Curriculum Corporation, 1994a) and the Science Profile (Curriculum Corporation, 1994b) have placed a particular emphasis on the development of inquiry and problem solving skills, as have similar national curriculum frameworks in North America, Canada, the United Kingdom and New Zealand. For example, the National Science Education Standards of the United States of America (National Academy of Sciences & National Research Council, 1996) outlines a national goal that all students should become scientifically literate, which means that a person can "ask, find or determine answers to questions derived from curiosity about everyday experiences" and can "evaluate the quality of scientific information on the basis of its sources and the methods used to generate it" (p. 22). Similarly the UK Science National Curriculum Orders include Experimental and Investigative Science as one of four attainment targets (School Curriculum and Assessment Authority, 1994). Lunetta and Tamir (1979) and Woolnough and Allsop (1985) have argued that to achieve such aims there is a need for teachers to match appropriate types of laboratory work to those aims.

The Working Scientifically strand of the Australian Science Profile describes the development of science investigation skills through eight levels. The Western Australian Monitoring Standards in Education project revealed that typical Year 10 students have only attained Level 3 and some of the simpler Level 4 science investigation skills (Education Department of Western Australia, 1994). Hackling and Garnett's research (1991) indicates that Western Australian secondary students "had poorly developed skills of problem analysis, planning and carrying out controlled experiments, basing conclusions only on obtained data, and recognising limitations in the methodology of their investigations" (p. 169). The low levels of investigation skills reported for Western Australian secondary students are likely to be related to the opportunity given through laboratory work to practise these skills; that is, the extent to which laboratory work is open to inquiry.

Laboratory activities can be classified by level of openness to inquiry according to whether the teacher prescribes the problem, the apparatus to be used, the procedure to be followed and the expected answer, or the students are required to make these decisions for themselves. A scale of openness to inquiry has been developed (Hegarty-Hazel, 1986; Tamir, 1989) to classify laboratory activities (Table 1). A scale was first devised by Schwab in 1962 and elaborated to include level zero, the lowest level of inquiry, by Herron in 1971 (Tamir, 1989). Hegarty-Hazel (1986) further elaborated the scale to divide level 2 into levels 2a and 2b to increase discrimination between levels of openness.

Table 1
Levels of Openness of Inquiry in Laboratory Activities (after Hegarty-Hazel, 1986)

Level	Problem	Apparatus	Procedure	Answer	Common name
0	Given	Given	Given	Given	Verification
1	Given	Given	Given	Open	Guided inquiry
2a	Given	Given	Open	Open	Open guided inquiry
2b	Given	Open	Open	Open	Open guided inquiry
3	Open	Open	Open	Open	Open inquiry

At the lowest level of inquiry (level 0), the problem to be investigated, the apparatus to be used, the procedure and the answer to the problem are all given to the students by the teacher or by a worksheet. At the highest level of inquiry (level 3), the students are required to determine all of these for themselves.

Analysis of laboratory manuals from North American inquiry based curricula such as BSCS and PSSC by Herron (1971) and Tamir and Lunetta (1978) revealed limited opportunities for open investigation work. Similarly, Friedler and Tamir's (1986) analysis of Israeli high school science laboratory manuals and classroom observations revealed that one third of activities were at level 0 and one half were at level 1 on Herron's (1971) scale, and "only rarely were students required to identify and formulate problems, to formulate hypotheses, to design experiments, and to work according to their own design" (p. 264). In a more recent study of North American high school laboratory manuals, Germann, Hoskins and Auls (1996) found that the manuals "seldom call upon students to use their knowledge and experience to pose questions, solve problems, investigate phenomena, or construct answers or generalisations" (p. 475).

Fraser, Giddings and McRobbie's (1995) Science Laboratory Environment Inventory (SLEI) was used to assess students' perceptions of various aspects of classroom environment in science laboratory lessons. Responding to the SLEI, upper secondary students from six different countries rated their science laboratory classes as having very low levels of open-endedness. Also using the SLEI, Hofstein, Cohen and Lazarowitz (1996) found that Israeli students rated biology laboratory classes to be more open ended than laboratory classes in chemistry.

This review of previous research involving analyses of laboratory manuals and studies of laboratory environments indicates that upper secondary science curricula offer few opportunities for open investigation work and the development of investigation and problem solving skills which are now emphasised in national curriculum statements and are at the heart of scientific literacy. As Richard Gott and his colleagues argue "to date science education has failed to make pupils aware of and familiar with the ideas surrounding the collection, validation and interpretation of objective evidence" (Gott, Duggan, Millar, & Lubben, 1995, p. 186).

Purpose and Research Questions

The purpose of this study is to extend previous research at the upper secondary level to the lower secondary science curriculum and collect baseline data regarding the level of openness of inquiry of laboratory work performed in metropolitan Perth schools, and to probe teachers' perceptions of the benefits and difficulties of implementing more open inquiry laboratory work. The specific research questions addressed were:

1. What level of inquiry do science teachers report they are using in laboratory activities?
2. Is there any difference of inquiry level reported for teachers: in different school systems; of different sex; with different teaching experience; from different teaching fields; teaching at different year levels; teaching different science disciplines?
3. What do teachers perceive to be the major benefits and difficulties for students and teachers of using laboratory activities at higher levels of openness to inquiry?

Method

A questionnaire was constructed to determine the openness of inquiry of the laboratory activities currently used in lower secondary science. Lower secondary science teachers in randomly sampled schools were asked to complete this questionnaire. It asked for demographic information, information about the level of inquiry that they use, and personal views on using open inquiry.

Participants

Teachers selected to participate in the questionnaire were those who taught lower school science classes in the randomly sampled schools. Teachers were selected from randomly selected schools because a list of individual teachers who taught lower secondary science in the Perth metropolitan area at the time of the study could not be readily obtained. From the 113 secondary schools in the metropolitan area (57 government, 26 catholic, and 30 other independent schools) 29 were randomly selected. The schools were contacted and invited to participate. All agreed to do so. From this contact it was determined that the sample comprised 247 lower secondary teachers. Of the 197 for whom data were eventually obtained, 125 were male and 72 were female; 124 taught in government schools and 73 taught in non-government schools.

Instrument

The questionnaire comprised three sections. The first section included questions about type of school, the teacher's sex, years of experience, and teaching specialisation. In the second section, questions asked the teacher to report on the last laboratory lesson that the teacher had taught. Questions asked about the year level of the class; whether the lesson related to biology, chemistry, earth science or physics; and whether the problem, apparatus, procedure and answer to the problem were given by the teacher or decided by the students. Teachers were also asked if the reported lesson was typical of those laboratory activities taught to the class. The third section involved more open-ended questions about teacher's beliefs regarding benefits and difficulties of open inquiry laboratory activities for students and teachers.

Nine university lecturers and teachers were consulted to establish appropriate wording for the questions. The questionnaire was also administered to nine teachers in a pilot study to improve the wording of the questions prior to the main study.

Data Analysis

In coding teachers' responses to questions about openness of inquiry, the frequencies of the various levels were recorded and examined. Responses to open-ended questions were placed into categories and frequencies of responses within the categories were recorded.

Grouping teachers or lessons according to school type, teacher's sex, teacher's main teaching field, teaching experience, year level and the lesson's main science discipline emphasis was carried out using the information supplied in the first part of the questionnaire.

Results and Discussion

Questionnaires were returned by 28 of the 29 schools. Of the 247 questionnaires mailed out 197 or 80% were returned and analysed. According to Gay (1981) a return rate of over 70% is acceptable for maintaining validity. Data are reported here for: frequency of reporting levels of inquiry; mean inquiry levels reported by type of school, teachers' sex, years of experience, and teaching specialisation; and perceived benefits and difficulties of open inquiry for students and teachers.

Levels of Inquiry Reported for Laboratory Activities

Table 2 shows the frequency with which teachers reported different levels of inquiry for their latest laboratory activity. Over one third of all lessons were of the verification type (level 0) where the teacher prescribes the problem, apparatus, procedure and the expected answer. The most common level of inquiry was level 1, in which the teacher prescribes the problem, apparatus and procedure to be used, but not the expected answer.

Table 2
Frequency and Percent of Use of Each Level of Inquiry

Level	Frequency (n=197)	Percent
0	73	37.1
1	92	46.7
2a	21	10.7
2b	8	4.1
3	3	1.5

Eighty-four percent of laboratory activities were either at level 0 or level 1. These laboratory activities provide students with the opportunity to practise following instructions, setting-up apparatus, making observations and measurements, presenting and interpreting results. In only 16% of activities did students have the opportunity to plan the experimental procedure. This high proportion of activities at levels 0 and 1 (84%) appears to be quite similar to previous analyses of upper secondary curricula (e.g., Friedler & Tamir, 1986).

When asked how representative this lesson was of those laboratory activities taught to their class, the vast majority of responses indicated that the lesson was quite typical. The breakdown of these responses is presented in Table 3.

Table 3
Teacher Rating (Frequency and Percent) of the Representativeness of the Identified Lesson

Rating of representativeness	Frequency (n=197)	Percent
Very well	94	47.7
Satisfactorily	98	49.8
Poorly	4	2.0
No response	1	0.5

Ninety-seven percent of respondents indicated that the activity on which they reported was typical of the activities taught to that class.

Differences Between Groups

A Kruskal-Wallis One-Way Analysis of Variance (ANOVA), a non-parametric test was used to examine the differences between the various groups. The results of Kruskal-Wallis One-Way ANOVA test (Table 4) showed that there was no statistically significant difference between the various groups other than that associated with the type of science subject taught. In other words there was no difference in the level of inquiry presented in laboratory work for government or non-government teachers, male or female teachers, inexperienced or experienced teachers, biological or physical science trained teachers, or the year level taught. There was a statistically significant difference, however, for the type of science subject taught at the 5% level.

Table 4
Kruskal-Wallis One-Way ANOVA for Differences in Level of Inquiry Between Different Groups

	N	Chi square	df
School type	197	0.002	1
Teacher sex	197	0.54	1
Teaching experience	197	0.58	4
Teaching field	197	1.09	3
Year level	197	2.79	2
Science subject	196	9.93*	3

* $p<.05$

The percentage of lessons that show some degree of openness to inquiry (levels 2a, 2b and 3) increases from earth science (one of 12 lessons, 8%), chemistry (13%), biology (17%) to physics (21%). These findings are consistent with those of Hofstein et al. (1996) who found that Israeli students rated biology laboratory classes to be more open ended than laboratory classes in chemistry. It may be that physics offers more opportunities for investigation style laboratory work than the other disciplines. It has been suggested (Garnett et al., 1995) that the ease of isolating and controlling variables in physics contexts facilitates the design of investigations for testing causal relationships; chemistry and earth science, however, offer less opportunity.

Table 5
Frequency of Levels of Inquiry for the Various Science Lessons in the Study

Subject		Level				
		0 (n=73)	1 (n=92)	2a (n=21)	2b (n=8)	3 (n=2)
Biology	n=48	16	24	6	2	-
Chemistry	n=84	37	36	9	2	-
Earth Science	n=12	8	3	-	-	1
Physics	n=52	12	29	6	4	1

Benefits and Difficulties of Open Inquiry

The benefits of higher levels of inquiry for students as perceived by teachers were grouped into categories of responses. The frequency of responses in each of the categories is presented in Table 6.

Table 6
Benefits of Higher Levels of Inquiry for Students as Perceived by Teachers

Type of benefit	Frequency of response (n = 412)
Greater interest / ownership / motivation	88
Students learn more / have greater understanding	84
Personal skills development	67
Learning scientific procedures and design	41
Useful for students of certain abilities	37
Sense of achievement / self-esteem	33
Develops problem solving skills	27
Promotes creativity	27
Real scientists' work	5
Variety	3

The greatest number of responses was in the greater interest/ownership/motivation category. This included responses such as: gives a feeling of involvement; presents a challenge; students own their work; intrinsically motivating; relevant to students; increased motivation because of ownership; and more enjoyable. Hodson (1990), Watts (1991) and Skinner (1994) have argued that student motivation and sense of ownership is greatest when students choose the context, problem and method of investigation. Teachers also recognised that more open laboratory work facilitates the learning of personal skills (67), skills of designing experiments (41) and problem solving skills (27). These learning outcomes are consistent with those espoused by the national curriculum statement.

Teachers also identified difficulties of higher levels of inquiry for students (Table 7). Almost half of the responses related to the theme; students can't work without set procedures. Students may need some form of cognitive scaffolding to make the transition from following the prescribed procedures of recipe style laboratory work to autonomous decision making within open investigation work (Vygotsky, 1978). Planning and report sheets (Hackling & Fairbrother, 1996; Watson & Fairbrother, 1993) with a sequence of open questions that structure the sequence of decision making steps for students can provide the scaffolding required for students to progress to open inquiry.

Table 7
Difficulties of Higher Levels of Inquiry for Students as Perceived by Teachers

Type of difficulty	Frequency of response (n = 148)
Students can't work without set procedures	71
Hard / impossible for students of low ability	31
Inaccuracies / misconceptions	14
Students don't share the workload	11
Problems of getting started	11
Other	10

It should be noted that 412 of the teachers' responses related to benefits and only 148 related to difficulties of higher levels of inquiry for students. When considering benefits and difficulties of higher levels of inquiry for teachers this picture was reversed with a greater number of responses relating to difficulties (386) than for benefits (122). Most of the difficulties for teachers were perceived to be related to curriculum and time constraints, equipment demands and management-safety issues. These data are presented in Tables 8 and 9.

Table 8
Benefits of Higher Levels of Inquiry for Teachers as Perceived by Teachers

Type of benefit	Frequency of response (n = 122)
More facilitating and less spoonfeeding	26
Better teaching and achievement of objectives	22
Students more on-task / motivated	18
Personal job satisfaction / reward	16
More time to circulate among students	14
Gauging students' understandings / skills	12
Less effort and time for teachers	11
Interest / variety for teachers	3

Perceived difficulties of implementing more open laboratory work reveal important potential barriers for teacher change; issues that must be addressed by curriculum development and professional development programs. Of the 386 responses, 99 related to perceived curriculum and time constraints, 84 dealt with equipment concerns and most of the remainder were associated with management issues.

Table 9
Difficulties of Higher Levels of Inquiry for Teachers as Perceived by Teachers

Type of difficulty	Frequency of response (n = 386)
Curriculum and time constraints	99
Equipment demands	84
Behaviour management / safety	74
Management of number of students / experiments	45
Organisation and preparation demands	33
Students require more help	16
Assessment	12
Students at different levels of completeness	7
Other	16

Curriculum and time constraints were grouped together because many teachers' comments linked the two within the one comment. This category contained comments such as: "Takes too long," "Takes longer for concepts to be covered," "Experiments digress from the curriculum," "curriculum constraints," "Curriculum too content packed," "Already enough to cover in the time available," "Curriculum materials are not sufficient for this" and "Must complete unit by the end of the term." The second most numerous category consisted of comments such as: "Too much diversity of equipment required," "Equipment not always available," "Too much to expect from the lab technicians," "Ordering in time" and "Students not aware of the materials available." The third category was made up of comments such as: "Students off-task," "Stimulates inappropriate behaviour," "Students too immature," "Students are not responsible enough," "Too dangerous," "More accidents" and "75% of the students would blow themselves up!"

The comments show that teachers believe that the use of more open inquiry is difficult, mostly because of curriculum time constraints, equipment demands, and behaviour and safety management problems. Open inquiry laboratory activities take longer than verification activities because they require the students to do more work for themselves. The teachers generally felt that there was not enough time to allow for the inquiry activities as there was too much content to be covered in the time available. The move from specifying curriculum frameworks as large numbers of objectives and statements of content to a small number of more general learning outcomes will give teachers the opportunity to select from the existing array of content to provide contexts for developing learning outcomes. For those schools and teachers who are ready to teach less better, time can be found in the curriculum for open investigations.

Teachers also believed that inquiry activities would create more classroom management problems. The use of planning and report sheets to structure student inquiry, and the development of cooperative group work skills may reduce teachers' concerns about management difficulties. Science curricula such as *Primary Investigations* (Australian Academy of Science, 1994) and *Middle School Science and Technology* (Biological Sciences Curriculum Study, 1994) provide useful models of how group work roles and the social skills necessary for effective group work can be developed.

Conclusion

In reviewing the science education middle school research for this century Helgeson (1994) states that:

> ... the most effective approach to teaching science appears to integrate science process skills and science content over several weeks, using hands-on, inquiry activities concentrating on specific problem-solving skills. Moreover, students who receive such instruction tend to learn more science and to develop more positive attitudes toward science and more self-confidence in their own abilities. (p. 262)

The sentiments expressed in this statement are ingrained in the national curriculum policy statements of a number of countries including the USA, UK, NZ and Australia.

In this Western Australian study, there would appear to be a gulf between the rhetoric of such curriculum policy documents and the realities that exist in the classroom. The study indicates that teachers are generally not using open inquiry activities in their lower secondary science lessons even though they are aware of the benefits. The reasons for this state of affairs centre on three main difficulties: curriculum and time constraints; equipment demands; and management problems. If the expectations of curriculum policy statements are to be achieved it is necessary that the concerns of classroom teachers are addressed. To do this will require the development of quality curriculum resources coupled with effective professional development strategies.

Quality curriculum resources can provide a concrete basis for demonstrating integrated inquiry activities with appropriate conceptual development approaches and strategies like cooperative learning that facilitate effective group work. A quality curriculum resource also needs effective professional development to help teachers change and develop the necessary expertise to implement a science program consistent with best practice. History has shown that without the introduction of curriculum resources and professional development little will change.

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