A MODEL FOR ASSESSING STUDENTS' SCIENCE PROCESS SKILLS DURING SCIENCE LAB WORK

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Abstract

The assessment of students' manipulation skills is often neglected by teachers. This trend can be partially attributed to traditional assessment practices which focus upon what the student writes in a lab report rather than the student's physical performance during the lab activity. Therefore, this article reports on the processes which were undertaken when designing the Performance-Based Lab Assessment Technique (PBLAT). The PBLAT can be used to assess the process skill of manipulation of equipment/materials in biology (i.e. assembling, measuring, and experimenting) as the students conduct science lab activities in high schools and colleges/universities. The PBLAT is not limited to biology lab situations as it can be adapted to other sciences.
Key words: *assessment, Lab work, process skills, science.*

Introduction

In science education, assessment is typically used to examine and describe student achievement and progress (Enger & Yager, 2001) in one or more of these six domains of science: *cognitive, psychomotor, application, affective, creativity and nature of science* (Carin & Bass, 1997; Enger & Yager, 2001; Trowbridge, Bybee & Powell, 2000). The *cognitive* domain of science includes accepted scientific constructs such as scientific laws, principles and theories. The *psychomotor* domain, often designated as performance or practical skills, includes science process skills such as: observing, manipulation of equipment/materials (assembling, measuring, and experimenting), classifying, communicating, inferring, predicting, identifying and controlling variables, interpreting data, and formulating hypotheses. The *application* domain requires the determination of the extent to which students can transfer what they have learned to a new situation, especially one in their own daily lives. The *affective* domain is primarily associated with explorations of human emotions, expression of personal feelings, decision making about personal values and about social and environmental issues. The *creativity* domain is essential to science as it is used by scientists in generating problems and hypothesis and in development of plans of action. Though creativity is a complex construct which is difficult to assess, it plays an integral role in doing science. Creativity calls for experience that promotes visualization (production of mental images), divergent thinking, consideration of alternative viewpoints, solving problems, and designing devices and machines. The domain of the *nature of science* is related to characteristics of science, knowing the world around us through empirical methods and how scientists think and work in the science community. Given the existence of the domains and their accompanying skills, it is worth asking the question: To what extent are the skills in the six domains of science formally assessed in a lab setting?

We will focus on the assessment of skills in the *psychomotor domain because it is directly associated with doing science in the labs – a theme for this paper*. Generally, skills in the *psychomotor* domain can be manifested and demonstrated by students through hands-on activities in the lab (Rezba, Sprangue, Fiel & Funk, 1995). As such, this domain is important in that it provides students with an opportunity to demonstrate their manipulation skills, and understanding of processes and concepts through doing lab activities. But to what extent are manipulation skills in *psychomotor* domain of science *explicitly* assessed during science labs in high schools or college/university settings?

Current Methods of Assessing Process Skills during Lab Work

Research shows that various methods have been used to assess students' achievement in science lab activities (e.g. Ferriman *et al*., 1994; Wynne, 1999). Some of these methods include: written lab reports - in form of open-response question, or multiple-choice (Doran, Chan, Tamir & Lenhardt, 2002), performance tasks, portfolios, and self/peer checklist (Rezba *et al*., 1995; Trowbridge *et al*., 2000), and investigative projects (National Research Council, 1996). The open-response questions require students to make observations, analyze investigations, solve problems and, construct their own responses in writing a report. Although teachers may provide formative instruction during the lab exercise and make assessments of the student's procedural ability, in the absence of a formal assessment of procedural ability, the teacher/instructor only assesses the students based on what they have written in the *lab report (end product)*, and ignores the actual *doing (the act)* during the lab. Performance-based assessments have been used to assess student achievement in science labs. Performance tasks involve students demonstrating their understanding through actual manipulation of equipment and materials in the laboratory. However, several authors have indicated that the actual doing of the lab activities is rarely assessed (e.g. Harden and Cairncross, 1980; Tobin et al., 1990; Wynne 1999; Moni et al., 2007). Portfolios have also been used to assess students in science labs. A portfolio is a collection of representative work including some evidence that the student has evaluated the quality of his or her own work. Portfolios may also include written work which shows students' growth in self-assessment and confidence. However, compilation and assessment of portfolios is very time consuming and difficult to manage. Of the various ways of assessing students' lab work, the most common and practiced method is the written lab reports which reinforces the primary importance of what the student is able to know in terms of factual knowledge rather than the performance of skills.

In a desired situation, the skills in the psychomotor domain would be assessed because instructors have information about how students do the lab and how well they do it. Several ways of ameliorating this have been outlined by some researchers. For example, Fleming et al. (1976) cited in Harden and Cairncross (1980) suggest that since practical skills represent an area where in-course assessment is applicable, then a miniature research project could be an assessment tool. However, this approach has been challenged by others who contended that students' progress and performance achievement may not be assessed adequately, because of the time lag and student would be working in collaboration with another person. In another instance, the National Research Council (1996) proposes that assessment activities be sequenced in such a way that similar skills are assessed over time to ensure that students have acquired them. Assessing similar skills would enable teachers to assess those students who were not assessed previously. In addition, teachers would be able to consistently monitor how well students have gained the relevant skill. Harden and Cairncross (1980) suggest another way which involves mounting different stations for students to move around and do the activity whilst the teacher or teaching assistant is observing how well they do the lab activities. These authors provided some great insights and cautions into how assessing process skills could be organized using the idea of stations. However, the stations model is not a panacea for assessing manipulation skills during science labs as the stations are an artificial construct that separates assessment of lab skills from the performance of the activity itself. Therefore, a design for assessing skills in psychomotor domain of science during science labs is needed.

Several reasons for the tendency to focus upon summative lab reports have been stated in the literature: persistent suspicion among teachers about the validity and reliability of the results of lab assessments (Harden & Cairncross, 1980); teachers' lack of skill in assessment, problems of practicability both in terms of class size (Moni *et al*, 2007); and the content-dominated view of science education in which content knowledge is believed to be worth measuring than the process students undergo during the lab activities (Wynne, 1999). In order to show how the content-dominated view of science education has defined lab assessment, Harden and Cairncross gave this illustration: if one objective of the course was that the student should be able to carry out the test for the presence of starch in a green leaf, it is likely that the student would be asked to write responses to questions such as: 'write notes on starch and the leaf'; 'describe how you can test for starch'. Though the last question seems to be more related to the objective, it is still a poor test of the students' practical competence because it is not asking the student to *carry out* the test. This kind of assessment has led to the assessment of performance problem in science labs.

It is apparent in literature that there is an *implicit* approach in assessing students' manipulative skills and in many cases it has been ignored by teachers (Lovitts & Champagne, 1990). This problem has been compounded by the assumption that a strong relationship exists between the knowledge about a task and actual performance of it. The skill of manipulating equipment/materials (assembling, measuring, and experimenting) is the most important one as it is through this that students are able to make observations, communicate, or interpret the results (Osborn & Tatcliffe, 2002). Yet, there is little evidence to show how these skills are assessed during science labs. Can students' manipulation skills be assessed only by looking at the text in the lab reports students submit for grading? It is anticipated that the correct answers students report in their reports are the product of what they did in the lab. It would be very difficult to assess how well they did it just by only looking at the written report because the *doing elements* such as observations, equipment manipulation/assembling may not be translated into a text. When an experimental result is correct, it may be acceptable to assume that the technique used to produce the result was performed well; however, when an experimental result is incorrect, the problem may lie either in the conceptual understanding or in the technique that produced the result. In these cases in the science lab, students may have conducted the experiment well but they have reported erroneous figures, perhaps due to faulty equipment or poor mathematical calculations. In such cases, students are given low grade and instructors consider the answers to be wrong, and consequently label the student as a low achiever, both in cognition and in performance. Therefore, assessing manipulative skills is important because it would help to countercheck whether the student got an incorrect answer for reasons other than due to faulty equipment or due to failure to manipulate the equipment. With reference to the aforementioned domains of science, the assessment of performance skills is important because it is through the performance of those skills that students develop knowledge that unlocks all the other lab based concepts. For these reasons we believe that assessing performance skills in the lab is an important part of the overall assessment and learning processes for science students.

This paper proposes an assessment model that can be used to effectively assess science process skills among students during their lab activities. Bearing in mind that there are a variety of process skills, the design discussed in this paper will be limited to considering three specific manipulations of equipment/materials skills (assembling, measuring, and experimenting). An alternative and equally valid approach would have been to focus on other skills such as weighing, transferring, and recording among others but we chose the former three. In particular, the focus is on the *actual doing* of these three skills of lab work by the students. It is anticipated that the proposed technique will reflect good educational practices and the desired student learning in science labs by providing a suggested systematic approach to assessing science process skills which can not be directly assessed through written reports, but only recognized or seen or ascertained when students are actually *doing* the lab activities. The assessment of process skills entails that teachers would be able to utilize information to make adjustments in their teaching in response to students' ideas and reasoning (Treagust, Jacobowitz, Gallagher & Parker, 2001) - a practice which is likely to bring about an improvement in science instruction. In addition, the assessment of science process skills would enable the teacher to

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know whether or not individual students have *learned how to* use certain equipment or materials as well as grasped the learning material (Lovitts & Champagne, 1990) – thereby enabling teachers to monitor their learning *how to do it* and skill acquisition. Finally, this paper contributes to the existing knowledge base on student learning and assessment in the science lab.

Design Process & Procedure

The development of this manipulation skills assessment technique followed a design framework suggested by Rhodes (2000). The framework has three stages: preparation, formulation, and the execution.

Preparation stage

Principally this stage involved four steps: reading relevant literature, relating our own experiences in science classrooms both at high school and university levels, describing the performance problem, and tabling the problem to peers for comments. By consulting relevant literature, we were able to identify assessments which required re-designing. In this case, we identified that teachers only assess students' written lab reports and not what they actually do in the labs. Thus, the assessment of manipulation skills was found to be one of the elements in psychomotor domain rarely assessed. Then we came up with the suggested design.

In order to articulate the performance problem identified, we used the *Problem-directed instructional design: a method* (Rhodes, 2000) as a guide. Using this guide, we were able to select the relevant aspects to address in the write up such as reasons for considering instructional change, the type of the design, the possible context, and the personnel involved in the instructional process. For example, we were able to identify that the instructional change was due to the current practices of assessment which does not take into the account process skills that students use in the lab. In addition, we were able to identify that the design is a conventional, teacher-mediated instruction which is prepared for school and college contexts. Furthermore, we became aware that the target audience includes the students, student teachers, college science instructors, high school teachers, science teacher educators, and college science lab teaching assistants. In addition, we were able to classify the problem as an *opportunity problem* which would bring about improvement in the acquisition of science skills amongst students.

After defining the problem, we then thought of sharing it with a group of three science educators to get suggestions and views, which shaped the design of the assessment tool. For example, during one of the discussions, we got suggestions that we would not assess all skills in one lab and that we were supposed to create a generic design that can easily be adopted for other science disciplines.

Formulation stage

During this stage, we took into account the following aspects of the design: writing down the performance problem; devising some alternative solutions to the problem; and choosing and writing down the best possible solution for the suggested design. However, bearing in mind that we reviewed three different alternatives to solving the problem (which are: a miniature research project, assessment of similar skills over time, and mounting different stations - each assessing a specific skill), we had a task of choosing only one, of which would be the best optimal for the design. In order to do this, we employed an *Engineering design* (Rhodes, 2000) where we laid out the variables which we thought are important when assessing students' manipulation skills during lab work. These variables are: adequate assessment of manipulation skill whilst the lab activity is going on, opportunity to correct the student on the spot, adequate monitoring of individual students, the ratio of students to the teacher, and the availability of materials. Then, we rated the three alternative solutions against these variables to check the extent to which each method satisfies the checklist, as tabulated in Table 1 below.

Table 1. Rating alternative assessments.

Variable	Alternative solutions to assessing manipulation skill		
	miniature research project	assessing similar skills over time	mounting different stations
Adequate assessment of manipulation skill whilst the lab activity is going on	X	X	√
Opportunity to correct individual students on the spot	X	X	√
Adequate monitoring of individual students on the spot	X	X	√
The ratio of students to the teacher	√	√	√
The availability of materials	√	√	√

Note: A checkmark (√) represents that the variable fits well in the method, whereas a cross (X) indicates that the variable does not fit well.

The decision on which assessment method would adequately assess the manipulation skills was based on two defining characteristics (a) that manipulation skills cannot be assessed from what the student has written down in a lab report, but through observing what each student is actually doing in the lab, and (b) that students have to be assessed and monitored individually in order to get a correct record of their performance. As such, method of mounting different stations did satisfy these two characteristics. For example, through this method students would demonstrate one skill at a time, and the teacher would be able to accurately record the ability level of each student. In addition, this design helps the teacher to actually measure the correct skills (such as how well the student measured the object using a rule) which cannot be translated into text (e.g. lab report). Furthermore, through this assessment technique, teachers would be made aware of not assuming that a student who has factual knowledge would definitely be good at the actual performance of the task.

Execution stage

In this stage, we described how the design would resolve the performance problem described above. We also explained how it would ensure reliability, validity, and practicability (as outlined in the Exemplar Performance-Based Lab Assessment Technique (PBLAT) design section below). In addition, we shared the design with three science education experts, again, for validity of the design.

Performance-Based Lab Assessment Technique (PBLAT)

The proposed assessment tool is aimed at assessing students' skills on how they manipulate equipment/materials (assembling, measuring, and experimenting). As such, the assessment tool is not aimed at replacing the current ways of assessing lab work but to supplement them. In this paper, a biology activity on finding the magnification and viewing the internal structure of the leaf under a microscope will be used as an example. Therefore, below are the three aspects of the design: the *structure*, *description* and *the exemplar PBLAT*.

Structure of the PBLAT design: The main steps in its design are:

- Identify expected knowledge and skills students should demonstrate in the lab in order for them to show that they are performing or doing the labs well;
- Identify the materials and equipment to be used;
- Choose an organization/arrangement of equipment and materials (whether in stations or not);
- Prepare an observation protocol/sheet in which you will indicate how each student ma-

nipulated the equipment or how well the student did it. This is important for two reasons: to avoid time wasting; and to make the tool usable even to large classes like those typical of first year college science classes (Knabb & Misquith, 2006; Moni *et al.*, 2007);

- In the observation sheet, include a section for overall comments; and
- Allocate points on the spot and remediate the identified problems with students so that the progression problem of process skills is minimized.

The structure of PBLT design provided above can be modified to fit any "manipulation" activity in the lab. This means that the description provided may not be exhaustive - but the teacher or instructor can add other components such as notes for the weaknesses identified.

Description of PBLAT design

To illustrate the PBLAT design we will use a lab on *Finding the magnification and viewing the internal structure of the leaf.*

- The PBLAT would require that the teacher put a series of stations which assess various skills applicable to a particular lab activity. For example, in this activity would require three different stations, each assessing one of the skills on how well students would (a) assemble the apparatus (e.g. focusing the microscope, selecting a leaf, and preparing a wet slide),(b) take measurements (e.g. measuring the width/length of the actual leaf, of the specimen -the drawn leaf, and making calculations), and (c) conduct a practical procedure/experiment (e.g. peeling off the skin of the leaf, putting the slide under the microscope, using the microscope at both 10X and 40X magnifications, observing the location of the cells in a leaf, and drawing the cells).
- Students would move around each station to carry out the tasks, and, at every station, each student would be assessed on how competent he/she is on the skill. In this lab activity, on the leaf, students would be able to start the lab activity from any of the three stations. However, if in an activity, one of the stations is dependent on the preceding station, the teacher would sequence the activity in such a way that the student waits for the first five minutes and complete the cycle five minutes later.
- Depending on the complexity of the skill to be assessed, the teacher can decide on how long each student would take at each of the stations. For example, the students may take only five minutes at a station requiring them to measure the lengths of the actual leaf, the length of the specimen (drawn leaf), and calculate the magnification. A bell could be used to alert students that they are supposed to move to new stations.
- Since all three stations involve manipulation skills, the teacher with other two assistants have to be present at each station as each student demonstrates the skill to assess her/him on the spot. However, the number of assistants can be increased if many stations are mounted.
- Depending on how large the lab room is several stations on each skill can be mounted. In addition, the number of stations would depend on: the number of students, the range of skills to be assessed, the time allocated to each station, the total time available for the lab activity, and the facilities and materials available.
- If the activity requires the use of expensive or hazard materials or non-available leaves due to climatic conditions, then the situation could be simulated at a station. For example, peeling the skin of a leaf from a poisonous plant can be shown by video, film loop, or computer and students can be asked to describe how to do the peeling.
- The teacher assesses the students' performance on every station using a checklist and scoring card. The checklist would show the process skills to be assessed and the scoring card would provide an opportunity for the teacher to rate how well the student has acquired the skill, or how much effort is still needed. However, Rezba *et al* (1995) state that performance assessment tasks can be scored in two ways: holistic and analytic scor-

ing. “Holistic scoring offers an overall judgment about the quality of the process skills displayed [whereas] analytic scoring looks at specific skills such as assembling, and experimenting” (Rezba *et al*., 1995, p. 255).

Exemplar PBLAT design

Experiment: This activity is aimed at assessing students’ performance on: assembling equipment/materials, measuring, and conducting a practical procedure on a task on f*inding the magnification and viewing the internal structure of the leaf*.

Materials and equipment required: Leaves from a recommended plant, slides and covers, rulers, knife/scissors, petri dishes, distilled water and microscopes.

Student name: ______________ Signature of teacher: _______________
Date: ______________ Course: _________________

Manipulation skills to be assessed	**Score**	**Rating**	**Skill not attempted**
1. Assembling equipment/materials			
a. focusing the microscope			
b. selecting a leaf			
c. preparing a wet slide			
2. Taking measurements			
a. on the width/length of the actual leaf			
b. on the width/length of the specimen leaf			
c. calculating the magnification of the leaf			
3. Experimenting (conducting a practical)			
a. cutting the leaf for easy peeling using the knife/scissors			
b. peeling off the skin of the leaf			
c. handling safety (i.e. how to hold the knife, the leaf, the slides)			
d. putting the slide under the microscope			
e. using the microscope at 10X and 40X magnifications to have clear view			
4. Appropriate manipulation skills were used while conducting the activity			
5. Appropriate manipulation skills were used to determine the activity’s outcome			
6. Additional experiences are needed to practice these skills (list them) --- ---			

Note: key to the score and rating scale

Score	Rating
3	Proficient performance
2	Limited proficiency: Can use but needs more practice
1	Cannot do or use: Needs more instruction and practice
0	Not applicable, not observed

Conclusions

Although the lab work has long been used in science instruction to involve students in concrete experiences with objects and concepts, the assessment part has mainly focused on written reports (after the fact). As such, manipulation skills are hardly assessed. The proposed assessment design is applicable in science lab activities where manipulative skills should be assessed. Though the PBLT has not been piloted in the actual lab setting, this design is executable because there are some ways of ensuring reliability, validity, and practicability. Reliability is ensured by using checklists to rate students' performance, and through using more than one instructor to assess students. With the PBLAT, it is possible to examine large numbers of students within a short time if well planned and with adequate number of instructors and teaching assistants.

And, because of the advance planning, checklists and scoring criteria it is possible to use other colleagues/ teaching assistants to assess students. It is also easy to train teaching assistants at university level to use this in science labs. Whilst the assessment may demand increased preparation time compared with other approaches to practical assessments, this is offset by the more efficient use of instructors' time on the day of the lab. In addition, the PBLAT will increase objectivity when assessing the students' work, provide an opportunity for a wider range of practical skills to be tested, provide an opportunity for instructors to know the specific skill(s) where a student has difficulties, and will enable students to learn how to apply the scientific process skills in everyday life.

Although this PBLAT is highly recommended for use in science labs it is not designed to completely replace the current methods of assessing lab work because this assessment technique mainly focuses on the actual doing and not other things like concepts. Therefore, it is meant to enrich the existing assessment devices for assessing lab work. PBLAT also renders itself to execution in any lab settings because it is open to modification to suit the existing situation regarding the nature of the lab, the nature of the students, and the course. It can also be used in pre-service science teacher education to train teachers how to assess students' process skills such as the equipment manipulation.

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