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Assessing practical laboratory skills in undergraduate molecular biology courses

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This study explored a new strategy of assessing laboratory skills in a molecular biology course to improve: student effort in preparation for and participation in laboratory work; valid evaluation of learning outcomes; and students' employment prospects through provision of evidence of their skills. Previously, assessment was based on written laboratory reports and examinations, not on the demonstration of practical skills *per se*. This action research project involved altering the assessment design so that a greater proportion of the marks was allocated to active participation and learning in the laboratory, partially replacing a single examination with direct observation of student participation and learning over a prolonged period of weekly laboratory sessions. We ascertained staff and students' perceptions of the new assessment processes by means of a Likert scale questionnaire, student focus group and individual staff interviews. Overall, students and staff evaluated the new assessment structure positively, citing fairness, authenticity and reward for effort. Results also revealed the need for specific training of staff in this form of assessment and indicated staff -student ratios made assessment burdensome. Four out of five students reported that an increased awareness of the importance of practical laboratory skills stimulated them to greater efforts to achieve.

Keywords: performance assessment, authentic assessment, laboratory skills, molecular biology, action research, theory/practice

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Introduction

This study reports on the relative merits of performance assessment of laboratory skills in a second-year Cellular and Molecular Biology undergraduate course. The study was conducted in two semesters over a two-year period. Traditionally, students of the Biological Sciences at Edith Cowan University, Western Australia, were assessed on their laboratory work by reports, write-ups, assignments and examinations which were mostly prepared outside of laboratory sessions. Reports and write-ups could include as many as 10 individual pieces of work, which, together, were normally worth some 30% of total marks. Students reported that this imposed a large workload for little reward. Further, traditional modes of assessment failed to address adequately the development of practical laboratory skills considered to be useful by employers. The action research project was based on an intervention that increased the focus on learning practical laboratory skills and sought to engage students in professional reflection about their theoretical and practical skills.

This study integrates thinking about science teaching, graduate employability and assessment practices. It also advances knowledge by reporting on the outcomes of an action research study about performance assessment. Accordingly, the study contributes to the scholarship of teaching and learning that was given impetus by Boyer (1990) who argued that the definition scholarship should include discovery research, application and the reintegration of knowledge through teaching.

This study is also informed by a discipline-based approach to university learning and teaching because it explores the implications of discipline-specific knowledge and skill development for assessment design. The focus of this study is molecular biology. The action research intervention introduced practical assessment of students' performance of relevant laboratory skills. This has the potential to influence graduate employability as many graduates find work in pathology, biotechnology or other laboratories, where daily activities are laboratory based. The study therefore engages with current concerns to enhance students' employability skills which have become the subject of considerable attention by governments around the world (Whelan et al. 2010).

In addition to being located in the traditions of scholarly teaching and skills development, this study reflects the shift in focus from teaching to learning in higher education. This has included greater attention to assessment as a way of learning, known as formative assessment. This differs from the evaluation of the outcomes of students' learning through summative assessment, which has been criticised for its limited usefulness in developing reflective learning because students do not receive feedback on their performance (Suskie, 2009). If the aim is to teach practical laboratory skills, then this may be best achieved by assessing those skills in the laboratory rather than assessing written laboratory reports or answers to examination questions.

The action research intervention in this study focused on formative assessment practice. It was designed to enhance learning through performance assessment and continuous feedback to students. Performance assessments asks

> students to demonstrate their skills rather than relate what they've learned through traditional tests...Performance assessments ... ask students to do real life tasks [such as] conducting realistic laboratory tests... Performance assessments ... merge learning and assessment (Suskie 2009: 26).

The concept of authentic and situated learning is relevant to formative, performance assessment. It adds a real-world dimension 'that can create the focus for the whole course of study – the activity does not necessarily supplement the course, it can be the course' (Herrington & Herrington 2006), which was the approach adopted in this study.

The Action Research Study

Aims

The specific aims of the action research intervention were to:

- enhance students' awareness and learning of the laboratory skills required for employability;
- improve the authenticity of assessment of laboratory skills by observing students' actual performances in the laboratories over a prolonged period of time (3x12 hours), rather than in a short written examination (3 hours);
- provide greater opportunities for deep rather than surface learning.

The purpose of the study was to ascertain what worked and why it worked in order to provide an evidence base for future changes in assessment in this course of study. Further, the aim was to contribute to the scholarship of teaching and learning by identifying the features of good practice in laboratory assessment.

The course and the students

Cellular and Molecular Biology is a compulsory second-year level course in the Bachelor of Science (Biological Sciences) degree. It is also taken by students studying biology as a second major as well as many science education students who are training to be teachers. The course therefore has a diverse student community numbering between 40 and 60 students. Delivery is on-campus over a 12 week period with weekly two hour lectures and three hour laboratory classes, constituting a quarter of a full time load. Students complete prescribed activities during the laboratory classes which are normally taught and assessed by part-time, contracts staff, in this case postgraduate students.

The course covers basic areas of knowledge in the cell and molecular sciences with the content prescribed as learning outcomes (Table 1). Being a practical science, application of theoretical knowledge to laboratory investigations and reporting are explicit in the learning outcomes (Table 1, outcomes 4 and 6).

Table 1. Learning outcomes for Cellular & Molecular Biology course. Note that general laboratory skills and data handling, as well as discipline-specific techniques are specified.

On completion of the unit students should be able to:
1. deduce the cellular and chemical bases of life on earth;
2. detail the structure of nucleic acids and the molecular structure of genes and chromosomes;
3. describe the processes of DNA transcription, translation, replication, repair and recombination;
4. demonstrate knowledge of and ability to apply important laboratory techniques for studying regulation of cellular functions: cell and viral cultures, recombinant DNA and genomics, genetic analysis;
5. outline the structure and function of biomembranes and eukaryotic cells;
6. display proficiency in data handling; laboratory skills and science communication.

Method

Action research projects are normally based on interventions that address a problem and give rise to improvements. The results can focus on both process and outcome. The intervention in this action research project made assessment the organising framework for a second year Cellular and Molecular Biology course. It involved a redesign of assessment with follow-up evaluation. As Table 2 indicates, prior to the study, assessment of practical laboratory skills and theoretical knowledge had been by written work only: reports, assignments and an examination at the end of the course of study. In brief, the learning and development of practical skills *per se* was previously not assessed. This deflected attention from the practical skills and risked surface rather than deep learning, especially in the case of assessment by examination. The new assessment design shifted the balance from completely written work, specifically the examination, towards direct observation of student participation and learning in weekly laboratory sessions over the period of one semester. A greater proportion of the marks was allocated to students' active participation and learning in laboratory work (40%). Written laboratory reports were retained in order to sustain and develop theoretical learning and report writing skills.

Table 2. Changes to assessment percentage weightings before and during the study.

Assessment item	Pre-study	Pilot	Full study
Laboratory			
*Participation/Results**	0	27	25
*Data analysis/Short answer questions**	18	33	15
Report	12	-	20
Sub-total	**30**	**60**	**60**
Assignment	**20**	**20**	**20**
Examination	**50**	**20**	**20**
Total	**100**	**100**	**100**

* These items consist of a cumulative assessment over the entire semester

This action research study incorporated both qualitative and quantitative methods in the form of surveys, participant observation and focus group discussion about the process and outcomes of the changed assessment design. Criteria for observing and measuring student learning and participation in laboratory activities and written work were developed in consultation with students and staff with the aim of increasing students' engagement with the objectives and outcomes of assessment and to encourage greater reflection on the development of their own skills. This approach was informed by the literature which indicates that it is vital for students to have a deep understanding of the assessment criteria and time must be allocated for students to develop this understanding (Brown et al. 1989; Dochy et al. 1999; Race 1998). The process was led by the lecturer to ensure that the assessment criteria covered important aspects and provide continuity between classes (years) (Tables 3 & 4).

Table 3. Foci for laboratory assessment developed by the lecturer

	Focus
1	Safe laboratory conduct
2	Competence in selected laboratory techniques
3	Ability to interpret results
4	Problem solving
5	Group work

A pilot study was conducted at the end of the first semester to trial a questionnaire, which had been designed to gain quantitative indicators of students' perceptions of the new assessment method using a five-point scale ranked from -100 (strongly disagree) to +100 (strongly agree) (Table 6). The score was derived by calculating the sum for all categories of the proportion of answers for each category multiplied by its value. In addition, there was room for student comments after each question. Further, one of the two staff members teaching the course was interviewed to ascertain how the new assessment processes affected staff. The results from the pilot were used to address any emergent issues before the implementation of a revised intervention in the following year.

Table 4. Assessment criteria for laboratory classes. Criteria were developed through consensus with students and teachers. Numbers in brackets refer to foci from Table 3.

Assessment criterion	Item
Evidence of preparation for the lab	Having read the lab notes
	Having brought reference materials where relevant
Being organised (2)	
Effective use of equipment	Safety awareness (1)
	Accuracy and awareness of procedures (2)
Appropriate behaviour	Safety awareness (1)
	Group dynamics (5)
Evidence of theoretical understanding of activities	Interpretation of results (3)
	Problem solving with regards to methods and techniques (4)

The same questionnaire was administered the following year, this time during, rather than after, the teaching period to maximise response rates. The responses from the questionnaire served as a basis for subsequent, in-depth exploration of emergent issues in a small focus group discussion. Staff were also interviewed, meaning that over the two year period three of the four staff were interviewed once.

Ethics clearance was gained under the rigorous processes of the Australian university at which the study took place. All interactions with students and staff and data transcription were undertaken by a person independent of all assessment in the unit, removing any means of identifying participating students. Students were given a disclosure statement and signed a consent form. It was made clear to students that their participation would have no effect on their marks in this or any other unit of study. Staff were informed that their participation would not influence future employment opportunities.

Results

Pilot Study

The pilot study revealed that both students and demonstrators considered that some laboratory classes had inadequate resources: students either had to wait to use equipment, or there was insufficient time or materials for all students to participate adequately. This compromised the assessment of student participation and was addressed by purchasing additional equipment and reorganising some of the laboratory work. Subsequently, this matter ceased to be a source of concern. Further, the staff member felt that the weighting of marks risked being unrepresentative of the time that students spent on particular tasks. He also thought that assessments in the first three weeks of the class were over-weighted relative to the second half of the semester. Upon his and the students' suggestions, a formal laboratory report in the style of a research paper was introduced, based on work in the second half of the semester. This is a complex task, linking practical application with theory through the use of relevant up-to-date peer reviewed literature. The laboratory report, therefore, reflected knowledge of theory more accurately than short answer questions in an examination and redistributed marks towards deeper learning. Two entire laboratory sessions were dedicated to workshops for the preparation of the laboratory report. The changes were generally viewed positively.

A significant outcome of the pilot study was that the staff workload associated with the new assessment system proved onerous. Students need considerable assistance with technical issues and problem solving, which is already difficult with a staff-student ratio of up to 1:20. Asking staff to provide detailed assessment at the same time became a problem. Whilst the staff member reported a more intense workload during laboratory time, this was compensated with reduced workloads outside of laboratory hours. His observations were that compared with the previous assessment structure, students appeared to put more work into assessment overall although the changed assessment structure had little perceived effect on student preparation for laboratory sessions. He also indicated that the new assessment patterns may have focused more on effort than on learned skills and knowledge.

The issue of preparation was addressed in later years by requiring students to prepare answers to set questions about the lab as well as experimental protocols and results tables. This was checked relatively quickly by the staff member during the class and was incorporated into the assessment. Overall, the staff member concluded that students appeared comfortable with being assessed in practical laboratory sessions. These were significant issues that helped to fine-tune the full action research intervention in the following year. For example, a matrix was developed for staff to facilitate note-taking on student performance on a weekly basis (Table 5). In addition, marks were subsequently allocated at only three points during the semester, each mark accumulated from work over several weeks. These changes eased the staff workload.

Only 17% (8/45) of enrolled students completed the pilot questionnaire. This relatively low response rate was due to the administration of the questionnaire after the end of semester. The results of the pilot study must, therefore, be treated with caution but they may be considered as fit-for-purpose to the extent that the results facilitated the fine tuning of the subsequent action research intervention. Respondents to the pilot questionnaire reported approval of the assessment structure (75%), believed that the assessment accurately reflected their knowledge and skills (87.5%), and said that continuous assessment is a more accurate reflection of their knowledge than a few assessment items (62.5%). Those who responded also believed that their workload was accurately reflected by the assessment weightings, that they increased their preparation for the laboratory classes, put in greater effort in the laboratory, were more aware of the links between theory and practice, and felt that the assessment helped them to develop a high level of proficiency with their lab skills. They reported being comfortable with being assessed by staff in the laboratory. When asked to comment on the best aspects of the new assessment processes the comments were specific: “It creates a challenging environment. It reflects current techniques used in the real world”.

Table 5. Laboratory assessment matrix for demonstrators. Note that the columns cover all assessment criteria listed in Table 3.

Week	Preparation				In-lab work			End-of-lab		Mark
Student	Punctuality	Protocols etc.	Understan-ding	Explanations	Competence & safety	Problem solving	Time management	Focus maintained	Tidy up	
A										
B										

Intervention Results

Some of the results were surprising. For example, it had been assumed that student participation in setting assessment criteria would find favour with the students: it is an egalitarian and collegial process that is known to enhance student engagement and learning outcomes (Nicol & MacFarlane-Dick 2006). However, only 47% of students were in agreement with the statement that being involved in setting the criteria for assessment led to a better understanding of the assessment process (Table 6). A significant proportion of students (37%) gave a neutral response to this question. Qualitative, written responses ranged from highly positive, "Absolutely. Then you know exactly what criteria you've worked for", to very negative, "I have never enjoyed being involved in setting criteria I prefer to be told by the lecturer what they want and to conform to that".

Others reported that they found the process confusing as they had little prior experience of consultative processes or of how to set assessment criteria. In contrast, students were in favour of the new assessment structure. They agreed that the assessment structure reflected knowledge, skills and workloads and that the assessment criteria were fair and reasonable (scores 29 and 43 respectively, agreement greater than 70%). In addition, students agreed that there was more incentive to develop laboratory skills and reported greater effort in preparation for laboratory classes and during the classes themselves (score >45, agreement >78%). The qualitative responses supported the quantitative results: "Because they're [laboratory classes] worth more, you put more effort in and you don't feel like you are wasting your time".

They agreed that staff evaluation of students' skills was fair and reliable (score 50, agreement 87%). Over 70% of students agreed that laboratory-based assessment was an accurate reflection of their knowledge and skills. Negative responses were generally not directly related to the laboratory assessment. For example, two students (5% of respondents) reported some discomfort at being assessed during the laboratory classes. In contrast, only one written response was negative: not all students had been assessed during the same class session, therefore potentially giving students different amounts of time to prepare; and peers could at times overhear feedback from the teacher. Both points have been addressed. The assessment is now broken down into individual sessions, with a final mark awarded to all students after a set number of weeks. In addition, feedback is provided discretely.

Table 6. Intervention Questionnaire Results

Question	Score	% agree/ strongly agree
The assessment structure supported achievement of the unit objectives	38	79
The weightings of the unit assessment items reflect the workload accurately	46	74
The unit assessment reflects my knowledge and skills accurately	29	71
Continuous assessment is a more accurate reflection of my knowledge and skills than few assessment items	54	82
The lab assessment encouraged me to develop laboratory skills to a high level of proficiency	47	79
Awareness of the increased importance of the laboratory component has resulted in greater preparation for the labs	50	84
Awareness of the weighting of the laboratory grade to the overall unit has resulted in greater effort to perform to a high standard during labs	57	82
The assessment of lab activities and reports resulted in a strong link between theory and practice	22	47
Being involved in setting the criteria for laboratory assessment helped me to a better understanding of the assessment process	12	47
The criteria for lab assessment were fair and reasonable	43	82
I was uncomfortable being assessed on my performance during labs*	29	68
The demonstrators were able to do the laboratory assessment in a fair and reliable way	50	87

* The answers for this question were reversed, as this was the only question asked in the negative.

Some dissatisfaction was expressed about the perceived lack of linkage between theory and practice (score 22, agreement 47%). This response is received in other courses without this particular assessment structure and appears to be because lecture content is not linked directly to laboratories on a weekly basis: some students find this confusing. However, other students noted that being asked to explain the rationale for experimental procedures improved their theoretical knowledge and understanding:

> "Yes, my knowledge and understanding increase greatly when I had to explain what I was doing and why".

> "I've learned more/understand more theory now than I have in any other lab because the theory is so linked with its application".

Students' identification of areas most in need of improvement varied widely. Responses pertaining to the laboratories included requests to strengthen links between laboratories and lectures. In contrast, 22 of 34 responses on the best aspect of the course identified the laboratory assessment, with additional comments referring to deeper learning, fairer assessment of the course overall, ability to develop workplace skills (put theory into practice) and a good alternative assessment for students without strong writing skills.

Points arising from the questionnaire were elaborated in a student focus group. The group's responses reinforced the outcomes from the questionnaire. Students were positive about the reduction of exam weighting and the benefits of continuous assessment:

> "Exams generally pointless…information is forgotten as soon as the exam is over. Lab assessment is cumulative, so you don't forget. If you don't understand at the start of a lab, you understand at the end. Knowledge is more practical".

> "Gives more confidence. Constant assessment and feedback helps you feel more confident about what you're doing. Explanation of exactly what is expected, and why something is marked in a certain way helps you focus on that certain part of your learning".

> "Workload is increased. Not extra work…but you really have to understand what you're doing. It's a valuable increase. Spread out over semester, so even though it's more work, you don't mind, because it means that you're understanding (more meaningful)".

Students also commented on improvements in their learning process:

> "Makes it so we can actually comprehend and understand, take it in and process it, rather than parroting it back".
>
> "Like sitting and talking to demonstrator, rather than writing a report. Get feedback immediately".
>
> "[Laboratory assessment] has been fair, they've done a good job. You get second chances…they check for improvement".

On the other hand, the increased focus on the laboratory component resulted in less effort in the theoretical aspects of the course discussed in lectures and assessed in the end-of-semester examination: "Lectures overwhelming. Don't seem to tie in…so it's really good that it's only worth 20%". This is a potential drawback of the change to the assessment structure. However, it is arguable that the previous structure was overly weighted towards theory and that the current structure provides a greater balance between theory and practice. A written assignment and laboratory report now provide additional assessments of theoretical understanding (Table 2).

Issues identified by staff focused mainly on their workload and the practicalities of implementing the assessment criteria. High staff-student ratios and the need to teach as well as assess during the laboratory session resulted in perfunctory assessment that risked being based more on reward for effort than learning outcomes. The main flaw, then, was the lack of time to assess carefully. Staff also found one of the assessment criteria – concerning student preparation for laboratory sessions - difficult to evaluate. One staff member developed a process for dealing with this by requiring all students to have a protocol prepared for the day's activities. This consists of a step-by-step detailed description of the activities for the session in the student's own words, incorporating tables for recording data. This was quickly and easily checked during the course of the lab session. In addition, staff used an assessment matrix consisting of a spreadsheet with a list of students and cells for recording observations on such things as presence, preparation, participation and understanding at each laboratory session. Staff worried that the majority of students were still not achieving the depth of understanding that they felt was required, but acknowledged that students made considerably more effort to understand the laboratories under the new assessment structure.

Analysis

The action research intervention was designed to change the weighting of marks and the assessment in one course of study to an approach that fostered demonstration of performance in laboratory settings. The changes have the potential to provide evidence of students' employability skills and to foster deep rather than surface learning. The aim of the study was to contribute to the scholarship of teaching and learning by identifying the features of good practice in laboratory assessment. So, what lessons may be learned from the action research intervention?

This study measured staff and student perceptions of the learning process. The results show that once the new assessment system was underway, students saw the benefits of the process with almost three-quarters of the student group agreeing that the assessment structure reflected knowledge, skills and workloads. Yet assessment based on observation in the laboratory faced obstacles because some students felt threatened by staff discussion of students' laboratory skills in the presence of their peers and staff felt pressured because they had to teach and assess at the same time. Even so, staff did note less pressure after class, when they would normally have been marking laboratory reports and exams. Problems were revealed through the pilot study and many were resolved before the main intervention in second year of the study. Revised strategies included observation and assessment matrices and assessment at fixed points in the semester based on cumulative marks to reduce pressure on staff. This implies the need to structure the process of performance assessment. To address students’ concerns, it became necessary to improve their learning environment by buying more laboratory equipment and by altering the timetable to allow equal opportunity for all students to be observed. This illustrates the importance of addressing contextual matters in any attempts to improve assessment because, as Bamber et al. (2009:3) indicated, ‘changing only an element at one level may have limited, local and provisional success ... because the rest of the system is not touched and established patterns prevail over the single change’. The lesson learned is that successful observation and assessment of students’ laboratory skills is partly contingent on the provision of structure through the development of templates and adequate resources including staff time.

Students certainly saw the advantages of receiving immediate feedback and working collegially with staff to improve their own learning: “You get second chances…they check for improvement”. This is particularly important for the current ‘Yuk/Wow’ generation of learners who need to be actively engaged in their learning to maintain interest (McWilliam, Poronnik & Taylor 2008). Even so, the emphasis on skills in the new assessment system was seen by some to detract from theoretical learning. This is important for university learning, because, as De Caprariis (2000) suggested, laboratory skills alone do not constitute science. Clearly, the implementation of assessment based on laboratory performance needs to be contextualised within the design of the whole learning program, including theory.

Any action research project involves the ‘plan, do and review’ cycle demonstrated in this study by the consistent development of new strategies and refinement of processes. For example, staff felt that there was a continuing lack of student preparedness for laboratories, implying an instrumental or surface approach to learning. Accordingly, one staff member developed a laboratory protocol to address this issue. Other strategies introduced as part of the action research cycle included matrices, timetable revisions, attention to learning spaces and a need to link theory and practice through curriculum design. Once again, this gives rise to the conclusion that the introduction of a new assessment system is not an isolated act. It occurs within a context (timetables, learning spaces) which must be addressed to ensure successful outcomes. The parameters of the context include universal principles associated with pedagogy about performance assessment and local circumstances:

> Effective change is embedded in context and comes when those involved make it their own through use and adaptation to local histories and contexts. Enhancements of practice are produced by a complex array of individually and collectively induced incentives, histories and values. A measure of control at the ground level is a condition of success. (Bamber et al. 2009)

The results of the present study problematise the ground level control advocated by Bamber et al. (2009). The intervention did invite students to participate in control of the assessment process by developing criteria and subsequently reflecting on their perceptions of the new assessment system. From a pedagogical point of view these processes should give rise to deep learning (Nicol & MacFarlane 2006; Race 1998) by engaging students in metacognitive processes that require them to think about their own learning. Yet, whilst some students favoured the transparency and clarity arising from the consultation process, others wanted staff to get on with the job of setting assessment criteria. There are other risks in ground level participation and control. For example, assessment criteria might vary year by year or course by course which may cause a credibility gap in universities required to demonstrate consistent standards. This risk was minimised by the lecturer ensuring that a vital set of criteria were covered.

This study has shown what can be done to develop authentic assessment of science students' laboratory skills. It is clear that it is important to create structures that get the context right for both staff and students. In this case, this meant providing a series of templates to address the many dimensions of learning from preparation for the laboratory session, to assessment matrices based on the criteria, and preparation for laboratory reports. It is also important to address learning spaces and to provide adequate resources for students to complete their tasks. Getting the context right also refers to training staff to complete this kind of assessment and to provide reasonable staff-student ratios and staff workloads. Finally, it is apparent that the introduction of a new assessment process is not an isolated act. Its success will be dependent on the design of the encompassing curriculum. The challenge is to design all dimensions of learning to encourage students to perform well at practical laboratory skills.

Conclusion

This study was contextualised and informed by the scholarship of learning and teaching, authentic learning pedagogies focused on the quality of student learning, and the importance of performance assessment in the development of the laboratory skills that will facilitate the employability of science students. It has revealed what staff and students think about in-lab assessment. It forms part of an action research cycle that invariably gives rise to further research. Next steps will examine the effects of performance assessment on learning. Do students learn practical skills better through formative, performance assessment than through summative report writing and examinations? In which ways can performance assessment improve links between theory and practice for students? What is the impact of reducing marks for written, theoretical assessment on students' learning? There is also scope to explore the impact of in-lab assessment on the quality of demonstrating and to evaluate how demonstrators might manage their time to ensure quality of teaching and assessment. What has been demonstrated in this study is the generally positive reception of performance assessment and the changes in context and preparation that are required for its successful implementation.

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