Integrating Assessment to Promote Engagement in an Introductory Chemistry Laboratory

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Abstract

Engaging and motivating students as they embark on their study of chemistry at university must be a primary objective of an introductory laboratory course, particularly for students with little or no background in the discipline. A cohort of 288 mature age students who had never previously been in a chemistry laboratory was given the opportunity to perform a series of chemical reactions in a laboratory session and to report on their experience. The group consisted of a mixture of part time and full time students who had just completed a one-semester introductory chemistry course. This paper describes an analysis of the student learning experience using the Advancing Science by Enhancing Learning in the Laboratory (ASELL) framework and explores the effect of an oral assessment on the student experience of the laboratory. A highly structured multi-task exercise was designed to engage and motivate students while simultaneously developing the skills of observing chemical transformations, communicating key observations, describing reactions using chemical equations, and in discussions with lecturers, reflecting on the underlying chemistry as part of their assessment. Analysis of survey results indicated increased confidence in laboratory skills along with a new awareness of the relevance of the practical aspects of chemistry. Over 90% of the participants rated the laboratory as excellent and indicated a high level of enjoyment. The results of this study demonstrate that the design of an introductory laboratory experience can integrate assessment that increases engagement and reflection on conceptual understanding. This has implications for successfully introducing the practical aspects of chemistry to students from a range of backgrounds.

Introduction

Australian university chemistry departments are facing increasing enrolments of students who have little or no chemistry background and may also have had limited experience with the sciences altogether. This includes mature age students and school leavers who find they are required to study chemistry as they move into undergraduate study in the fields of nursing, biomedicine, allied health, engineering and teaching. Since 2008, the driving force behind this growth has been the shift to a demand driven system in the Australian higher education system (Bradley, Noonan, Nugent & Scales, 2008). Sellar, Gale and Parker (2011 p.37) state “When HE [higher education] systems expand or widen their student population they must often engage groups who have not previously pursued university study in large numbers”. It is expected that this widening participation agenda will continue to attract many new candidates to the sciences and in particular to chemistry, which is an essential component of many health courses. For chemistry educators, these increasingly diverse cohorts bring with them numerous challenges, including how to effectively engage with the chemistry content (Bridgeman, Rutledge & Todd, 2006) and also how to give the most benefit to chemistry non-majors from undertaking a laboratory exercise.

There is considerable debate amongst educators about the impact of the chemistry laboratory experience on conceptual knowledge and skill acquisition. In particular, Hofstein and Lunetta (1982, 2004) have advocated for more careful design of laboratory experiments to improve understanding. Also, questions are often asked about the value gained for the amount of time, resources and money spent on undergraduate chemistry laboratories (Hawkes 2004, Reid & Shah, 2007). Teo, Tan, Yan, Teo and Yeo (2014, p. 246) have observed that depending on the type of laboratory work there may be limited impact on the students' science learning and that undergraduate students tend to miss the link between the practical and the theory. In addition, for non-majors, Hawkes (2004) suggests that the manipulative skills learned are not relevant, stating "we should not provide [labs] in preference to the other teaching for which time and resources could be used." (p. 1257).

A possible solution to this problem comes from a review of laboratory work in chemistry by Reid and Shah (2007, p.175). These authors noted, "there is a tendency for specialists to think in terms of presenting their subject rather than meeting students' needs." This suggests that innovative planning is required to adapt the subject material to engage students, cognisant that "learning in the laboratory is complementary to, yet different from learning outside the laboratory." (Galloway & Bretz, 2015, p.1149). Such planning has been attempted in this project for a particular group of students, those with little or no laboratory experience.

It is common for students who are not recent school leavers or have not studied chemistry to struggle with many of the concepts in chemistry and this contributes to their uncertainty about what they will encounter in the laboratory. For pre-university students the "inputs of information in the first laboratory are huge" and the "ability to plough through a recipe experiment line by line can be regarded as a major achievement in such circumstances." (Bennett & O'Neale, 1998, p.59). Thus, it is understandable that many of these students lack confidence in their ability to perform to a level that will give them a satisfactory score in any form of practical assessment, and that they display considerable apprehension about being assessed on their performance in the practical setting (Bridgeman et al., 2006; Naiker, Wakeling & Aldred, 2013, p.171). Tasks such as handling delicate equipment, making accurate observations and data recordings can present a daunting hurdle to their initial engagement with the subject (Sere, 2002, p.629). However, as Lim (2013, p.1) states, "laboratories are the signature pedagogy in chemistry education". If not given the opportunity to experience the laboratory setting, chemistry will appear purely abstract and theoretical (Reid & Shah, 2007 p.174). For these reasons this paper argues that chemistry students, including non-majors as well as learners new to chemistry, should be given the opportunity to experience the laboratory. While they may be inexperienced, mature age students are usually enthusiastic about embarking on their chemistry study and with appropriate guidance and feedback in the laboratory setting they can be helped to manage the many simultaneous and varied aspects of learning that occur in that environment. This study investigates how the design of a laboratory practical can engage inexperienced pre-university or introductory chemistry students, and how the incorporation of an oral assessment into the exercise can increase student motivation and ensure an efficient and worthwhile learning experience for the students.

In relation to communication skills, the Science Threshold Learning Outcomes state that upon completion of a bachelor degree in science, graduates will:

> *Be effective communicators of science by:*
> *4.1 Communicating scientific results, information, or arguments to a range of audiences, for a range of purposes, and using a variety of modes* (Jones, Yates & Kelder, 2011).

In an attempt to assess communication skills together with the level of conceptual knowledge held, an informal type of oral assessment was integrated into this laboratory session. The goal of this assessment, which was explained to students, was for the students and the lecturers to work together to ensure an effective learning experience. One unique aspect of this laboratory experience was that the course lecturers were the demonstrators. By integrating this type of assessment as part of a guided learning experience it was hoped the students would be able to focus on any conceptual difficulties and use the immediate feedback to improve their learning (Brown, Bull & Pendlebury, 1997). This formative assessment method reflects the findings that an assessment culture in education should focus on assessment *for* learning rather than assessment *of* learning (Black, Harrison, Lee, Marshall & William, 2004: Bryan & Clegg, 2006). Further, providing students with the opportunity to report orally on the important skills and knowledge contained within the laboratory session "embeds assessment and instruction" (Bensley & Murtagh, 2012, p. 6-16).

The focus in the design of this laboratory practical was to challenge students to conceptualise what was happening in the chemical reactions which were taking place in front of them. In consultation with the student, observations were checked and competency was then indicated on the student worksheet. In this way lecturers were able to act as 'researchers in the field', assessing students' ability by having meaningful conversations about their experimental observations in an informal semi-structured interview. This type of oral assessment is considered a "collective process that eliminates hierarchical arrangements" (Halinen, Ruohoniemi, Katajavuori & Virtanen, 2013, p. 21). In this scenario students and lecturers are seen as a collaborative team working to check capabilities and assessing conceptual understanding together. This ensures that students are able to gain immediate individual feedback concerning their ability to perform in the laboratory setting rather than waiting for a laboratory report to be marked and returned at a later date. By using the opportunity to discuss any difficulties *in situ* the lecturer and student can make efficient use of the laboratory time as an opportunity to build scientific literacy and communication skills. This also gives students more control of their learning processes, greater confidence and a stronger commitment to learning (Lindstrom & Sharma, 2010; Zepke & Leach, 2010). Research by Trigwell, Ellis and Han (2012) has indicated that students who are engaged in the learning process experience higher levels of positive emotions, use deeper learning strategies and achieve better learning outcomes. By having an active role in the assessment process the students should develop greater confidence in their ability to succeed in the laboratory.

Although oral assessment can be daunting for students, particularly introductory students, it was hoped that an informal interview aimed at improving confidence and competency would enhance the learning experience of the students. This paper describes the analysis of the responses to a student survey on the laboratory and aims to:

- Investigate students' perceptions of the laboratory learning experience;
- Examine the effectiveness of the oral assessment component in determining level of competency in conceptual understanding, laboratory technique and scientific communication skills;

- Determine whether one specifically designed laboratory practical can engage a diverse student cohort with a limited background in chemistry; and
- Investigate whether mode of attendance (full time or part time) has any impact on student engagement with the laboratory activity.

Study Context

The students in this study were completing an open-access pathway at a large regional university in Australia where there are no prerequisites or entry requirements other than a minimum age requirement of 20 years. The program offers pre-university courses to mature age students who, if successful, subsequently gain entry to and undertake undergraduate study at universities across Australia. The students are able to complete their studies in either part-time mode across one year or full-time mode in one semester. Chemistry is one of six science courses that students have the option of choosing within the program. The practical laboratory session in this project is the only chemistry laboratory session these students perform prior to entering their undergraduate study. For this reason the laboratory practical needs to both achieve student engagement by being relevant to their learning and act as a useful assessment tool for both students and course designers Most importantly for students continuing into science undergraduate programs, the laboratory session should deliver a positive message about the value and effectiveness of laboratory learning.

Methodology

Because this was the first time a laboratory exercise was to be implemented for these pre-university students and was therefore a pilot study it was decided to trial the experimental design at an ASELL workshop. The ASELL methodology assists in the design of laboratory practicals and assesses their effectiveness prior to implementation (http://www.asell.org/ASELL-Workshops/About-ASELL-Workshops.).
This approach produces two sets of data:

1. Comments and amendments to the design and content of the laboratory practical based on testing by academics in a university workshop.
2. Collection and evaluation of survey data relating to the student experience of the laboratory at the home institution.

The ASELL approach also provides the framework to identify and integrate learning outcomes in the design of a laboratory (see Appendix 1: Educational analysis. Table of Intended Learning Outcomes). By reflecting on the learning outcomes and the design of the experience from a learner-focussed perspective it was possible to design a pedagogically sound laboratory practical experience. The comments and feedback from the ASELL workshop delegates were constructive and contributed to the refinement of the laboratory practical by indicating several areas for improvement including a molecular modelling exercise for students, and providing an extension activity that students could choose to do.

Overall the laboratory practical was considered by the ASELL delegates to be an excellent way to demonstrate the link between the practical and the theoretical in the context of an introductory course and this cohort of students. Importantly, the workshop delegates commented that the experiments in the practical should help build confidence in students with little or no background in chemistry and were the most positive aspect in the design. For example, one of the ASELL delegates reported:

> *This lab is fun, builds confidence in technique and the application of basic theoretical concepts to the practical. For example using equations to describe observed reactions.*

Although discussed at the ASELL workshop, the oral assessment component was not evaluated by the workshop delegates and was based on a pedagogical decision made by the course designers at a later date. Students were surveyed after completing the exercise to assess whether the oral assessment had a positive or negative impact on the level of engagement.

The Design of the Laboratory Practical

The laboratory practical was centred on observing and recording chemical changes. Students were required to record all observations and complete balanced equations for six different chemical reactions plus one modelling exercise (full technical notes are provided in Appendix 2). The reaction setups were placed at different stations around the laboratory and included:

1. Metal plus an acid (magnesium plus hydrochloric acid)
2. Acid plus carbonate (calcium carbonate plus hydrochloric acid)
3. Precipitation reaction (sodium chloride plus silver nitrate)
4. Decomposition reaction (hydrogen peroxide)
5. Neutralisation reaction (hydrochloric acid plus sodium hydroxide)
6. Endothermic and exothermic reactions
7. Building isomers of pentane

These reactions were chosen because they illustrate some of the key concepts the students had been studying and were appropriate to the level of skill of the students. Balanced equations were to be recorded accurately using correct formulae including listing the states of the reactants and products (e.g. g, s, aq). Marks were awarded for correctly balanced equations for each of the reactions (see Appendix 3, Student Laboratory Workbook Excerpt).The marks for the laboratory report contributed 5% towards the students' final grade for the subject. It was intended that each activity would require 15 minutes, except activity 7 which only required 10 minutes. Each student should be able to complete all the activities in 100-110 minutes leaving 10 minutes of the two hour session to complete an individual oral assessment. Students worked in groups of three or four moving from station to station. With four lecturers per session of 40 students, each lecturer interviewed a total of 10 students individually for three to four minutes each. This required around 40 minutes per two hour session.

Assessment

The purpose of the assessment, that this was an assessment *for* learning, together with the fact that it was consultative, was clearly explained to the students prior to the laboratory session. Students were told that the lecturer would initiate the discussion around items such as manual dexterity, experimental technique, ability to follow procedure and orderliness (Eglen & Kempa, 1974). Students were also informed that the questions would be based on the conceptual material as well as the procedures related to the reactions they were observing. Lecturers could refer to the table of educational outcomes and asked students to self-assess their level of competency in performing the experiment. Appropriate questions included "how well do you think you are able to follow the procedure?" and "how would you rate your manual dexterity?". Lecturers were able to challenge students by asking them to explain what was happening in the reaction at either the station they were working at or one of the other stations they had completed. This assessment process took less than four minutes per student and occurred either as the student was completing and recording their observations prior to moving to the next station or at the end of the session. Figure 1 shows the form used for recording marks and comments during the laboratory session.

EPCHEM137/314 Chemistry

Laboratory Session:
"Starting to think like a Chemist"

Observing and Recording Chemical Reactions
Physical and Chemical Changes

Student Name:	
Student Number:	
Oral Questions **Comments:**	**Competent** **Not Demonstrated**
Marking: ***Total***	*2 marks per balanced equation* ..../10
Demonstrator Signature:	

Figure 1. Marking form for laboratory session including oral assessment.

It was possible for a student to gain full marks for correctly balancing the equations and yet not demonstrate accurate observational, procedural and communication skills. If the student had followed all the instructions, completed the equations for the reaction correctly and was able to clearly explain or discuss the reaction and the procedure, they were marked as competent. Where the student did not feel that they understood the reaction or the procedure, or if communication was poor, they were marked "not demonstrated" and an appropriate comment was recorded. For example:

1. Your observations have not been recorded accurately.
2. You have not completed all the observations.
3. Check your understanding of a neutralisation reaction.
4. You did not follow the procedure correctly.
5. You need to be able clearly explain your experimental technique.

In this way the student was self-assessing and gaining immediate feedback about their individual level of skill rather than just a summative mark. The value of this type of assessment is that it provides encouragement towards student self-reflection and communication skills.

Data Collection and Instrumentation

The sample consisted of full-time students (N=145) and part-time students (N =143). In both cohorts the age range was 20-40 years with an average age of 24 years. Along with the laboratory design framework, ASELL also provides a suite of survey instruments that can be used to gauge the student perceptions of the laboratory experience (Buntine & Read, 2007; Jamie et al., 2007; Yeung et al., 2011). Students were asked to complete the ASELL Student Laboratory Experience Survey (ASLE) (Barrie et al., 2015), which contains 14 five-point Likert-items and five open-ended questions. Items 1-12 are given a Likert scale from 'strongly agree' to 'neutral' to 'strongly disagree'. Item 13 about the time available for the experiment is given a Likert scale from 'way too much' to 'about right' to 'nowhere near enough'. Item 14 asks about the overall laboratory experience and is also given a Likert scale from 'excellent' to 'average' to 'very poor'. In order to obtain qualitative data, students were also asked to respond to the following open-ended questions :

Item 15. Did you enjoy doing the experiment? Why or why not?
Item 16. What did you think was the main lesson to be learnt from the experiment?
Item 17. What aspects of the experiment did you find most enjoyable and interesting?
Item 18. What aspects of the experiment need improvement and what changes would you suggest?

Finally students were invited to provide additional comments (Item 19). These qualitative responses were analysed using a method similar to that outlined in Buntine and Read (2007).

Results and Discussion

ASLE Likert data

A total of 284 students completed the survey from an enrolment of 288, including the open-ended responses, a return rate of 97%. Table 1 below compares the responses of the full-time and the part-time students for the first 12 items on the ASLE survey. The percentage of strongly agree/agree are combined to provide 'overall agreement' and strongly disagree /disagree are combined to provide 'overall disagreement'. Chi-squared analysis confirmed that the distribution of student ratings between the part time and full-time students was not significantly different (χ^2 =0.80, df =2, p=0.67). Item 8,'the demonstrators offered effective support and guidance', rated the highest in both cohorts, followed by item 10, 'I can see the relevance of this experiment to my chemistry studies', and item 2, 'this experiment has helped me to develop my laboratory skills'.

The Likert items 13 and 14 on the ASLE survey are measured on different scales as described above. The time available to complete the experiment (item 13) was "about right" for 82% of both part time and full time cohorts. For item 14 over 90% of both the part time and the full time student cohorts rated the experiment an excellent or a good learning experience. Chi-squared analysis confirmed that the distribution of student ratings between the two groups of students was not significantly different for overall learning experience (χ^2 =0.056, df=2, p=0.97).

The most striking aspect of the data was the overwhelmingly positive response from the 284 students who completed the survey. One of the questions posed for this study was whether the student mode of attendance had any impact on the overall level of engagement. Analysis of the Likert scale responses indicated that there was no statistically significant difference between full time and part time students despite the latter having to complete the laboratory practical session on an evening, often after a full day at work elsewhere.

Table 1. Percentage of part time and full time student responses to items 1-12 on the ASLE survey.

Items 1-12	Part time students			Full time students		
	SA/A	N	D/SD	SA/A	N	D/SD
1. This experiment has helped me to develop my data interpretation skills	93%	6%	1%	91%	8%	1%
2. This experiment has helped me to develop my laboratory skills	96%	4%	0%	97%	3%	0%
3. I found this to be an interesting experiment	95%	4%	1%	96%	4%	0%
4. It was clear to me how this laboratory exercise would be assessed	97%	3%	0%	93%	7%	0%
5. It was clear to me what I was expected to learn from completing this experiment	96%	4%	0%	94%	6%	0%
6. Completing this experiment has increased my understanding of chemistry	90%	9%	1%	90%	9%	1%
7. Sufficient background information, of an appropriate standard, is provided	94%	6%	0%	92%	8%	1%
8. The demonstrators offered effective support and guidance	99%	1%	0%	98%	2%	0%
9. The experimental procedure was clearly explained in the lab manual or notes	97%	3%	0%	95%	5%	0%
10. I can see the relevance of this experiment to my chemistry studies	98%	2%	0%	97%	2%	1%
11. Working in a team to complete this experiment was beneficial	97%	3%	0%	94%	5%	1%
12. The experiment provided me with the opportunity to take responsibility for my own learning	97%	3%	0%	94%	6%	0%

Student responses to open-ended questions in the ASLE survey

The students' written comments to the open-ended questions were classified according to identified broad themes and whether the content of comments was positive or negative in relation to that theme (see Table 2). The highest number of the responses fell into the 'interest and engagement' category with 232 individual comments. There was little difference in the number of responses in the 'experience of an experiment' (145), kinaesthetic (146) and 'understanding of chemistry' (128). The categories 'teamwork' (19) and 'potential for improvement' (20) had the lowest number of responses. It was reassuring to read the large number of positive comments about the hands-on, kinaesthetic aspect of the laboratory practical which indicate a high level of appreciation of the sensory experience, such as the speed of reactions, the rapid measurable temperature changes and the colour changes. Student comments about the sensory experiences of the reactions included "*It was great to actually watch a chemical change*", (and) "*to feel the test tube change temperature*", (and) "*now I know what a precipitate looks like*" (as well as) "*actually experiencing the speed of the reaction*".

Table 2. Summary of categories used in content analysis of the ASLE open response items. Numbers of comments in sub categories are in brackets.

Category Name	Total Comments	Sub Categories
Interest and engagement (IE)	232	Enjoyable experience (42) Great first experience in a lab (56) Better than sitting in lectures (24) Easy to follow instructions (12) Alleviated fear of laboratory (56) Interesting stress-free way to learn chemistry (42)
Kinaesthetic/ Hands on/ Visual (K)	146	Building molecular models (26) Seeing/hearing reactions (38) Visual aid to understanding chemical changes (41) Feeling the temperature change in the test tube (19) Watching the speed of reactions (22)
Understanding of chemistry (UC)	128	Techniques for identifying different gases (21) Now I understand isomers (18) Using balanced equations to describe observations (27) Chemicals react to form new substances (18) Energy is released in chemical reactions (3) How a catalyst works (19) Different classes of reactions (22)
Experience of experiment (EE)	145	Laboratory skill improvement (41) Handling scientific apparatus (32) Accurate observation and recording (27) Correct laboratory safety procedures (21) Critical thinking (3) Following instructions (5) Collecting gases (16)
Teamwork (TW)	19	Appreciation of help from classmates (5) Great to interact and share ideas (3) More efficient use of time as a team (11)
Potential for improvement (PI)	20	More experimental stations (3) More time for experiments (9) Less time for experiments (3) More lab sessions (3) More complex experiments (2)
Miscellaneous (M)	23	Supportive demonstrators (20) Pre-read lab notes (1) Importance of PPE (1) Enjoyed oral questions (1)

In response to item 16 'What did you think was the main lesson to be learnt from the experiment?', students responded with statements such as 'Laboratory skill improvement' 'handling scientific apparatus' and 'accurate observation and recording'. There were 128 individual student comments on specific chemical concepts such as 'understanding isomers' and that there are 'different classes of reactions'.

In the open-response questions, the 'interest and engagement' category received the most comments overall. Comments indicated a preference for hands-on 'real life experiences' rather than purely theoretical input from lectures and tutorials. Thus, it was the actual experience of performing a chemical reaction and observing the results that students enjoyed. Students' positive responses indicated recognition of the value of the practical experience and its relevance to their study in chemistry. As a result they reported that they were able to participate in a meaningful way, increasing their engagement with the subject. Contrary to the findings by Sere (2002) that students with little understanding of the purpose of the apparatus and procedures were unable to engage, this study was able to demonstrate that a specifically designed laboratory practical can provide a meaningful learning experience for students with a limited background in the subject.

In addition, there were 145 different comments about the practical aspects of performing the experiments such as developing scientific thinking skills in observation and data collection and identifying chemical hazards and risks. One student commented, "*It was good to actually see that what I had studied was not just a vague collection of esoteric concepts but something I could actually do myself in the laboratory!"*

Student responses to lecturers' oral questioning

Having been involved in the design of the laboratory practical, the lecturers were aware of the influence that questioning techniques might have on student responses and were able to direct the conversations in a way that kept the focus on the main concepts. Typical questions included "Can you explain what was happening in the acid base reaction?" or "What was the catalyst in the decomposition reaction and how it is involved in the reaction?" The assessment process was thus an opportunity to discuss their observations with the lecturer and 'clear up' any conceptual misunderstandings immediately. This was then followed by a discussion with the student about how and where the student could improve their skill level.

In their discussions with students the lecturers were able to check that all observations had been recorded accurately and that balanced equations were correctly written and then make a judgment regarding students' communication skills based on the their answers to the questions. Over 90% positive responses to item 4 (Table 1) indicated that students understood the procedure regarding the oral assessment. There were no negative comments regarding this aspect of the experience recorded on any of the surveys; in fact one student commented, "*It was good to find out where I am at and that I need to improve my communication skills"*.

Almost all students agreed with item 8 (Table 1), that the demonstrators (lecturers in this case) offered effective guidance. It seems that this interaction, regardless of the fact that it was a form of assessment, led to high levels of engagement with the material. The lecturers were able to use oral questioning to ascertain the level of conceptual understanding, communication skills and laboratory technique. The students were given a competent or not demonstrated comment based on their explanations of the reactions, their conceptual understanding and their laboratory skills, which allowed them to reflect and determine which skills needed improving. This shared reflection provided the opportunity for students to become responsible for their learning, creating a culture in which the assessment was focussed on learning rather than grades (Czekanski & Zane, 2013). Importantly there was an opportunity for a scientific conversation with each student, probing students' knowledge of chemical concepts while supporting the development of skills and building confidence. The student comments in the open response section of the survey regarding supportive demonstrators (Table 2) are an indication that the assessment component of the experience did not have a negative impact on the student experience. This type of assessment in the laboratory setting shifted the emphasis away from "*getting it right so that I pass*" to "*checking that I have the skills and am learning how to do it*". As such, this type of assessment can be a valuable pedagogical tool to enhance student engagement with the content while developing a capacity for self-evaluation. Being involved in the assessment of their own laboratory skills may also have had a positive impact on the students' level of engagement (items 4 and 12 in Table 1).

The fact that the lecturers were the demonstrators was an important aspect of the design of the laboratory practical. This could be problematic because there is a possibility that different lecturers may place different weightings on the mix of observational and communication skills. However, at this introductory level the focus was not on the mark but on the discussion with the student about their own performance and development of skills.

In the post-laboratory meeting the lecturers reported that although not yet fully competent, most of the students were able to describe the reactions they had performed, discuss their skill level and make reasonable attempts to explain the chemical concepts involved. There was no formal data collected from the lecturers and this will be addressed in future iterations of the laboratory exercise.

While there were no negative comments regarding the assessment component of the laboratory session, it is possible that this may be due to the inexperienced nature of this particular cohort of students who had not undergone any previous laboratory practical assessment. A more experienced chemistry student who had never experienced oral assessment may complain that this intervention is stressful or not effective.

Conclusions and future work

The primary educational objectives of this laboratory practical were to engage a diverse cohort of students with some fundamental chemistry concepts and to provide the opportunity to learn elementary laboratory and communication skills. The assessment of competence level was used as a self-reflective tool so that both students and academics could appreciate the value of the experience to student learning. It was not designed to be a comprehensive in-depth assessment of a skill set, but rather an innovative intervention to add an extra dimension to an introductory laboratory exercise. One of the limitations of this type of oral assessment is maintaining consistency between different lecturers. However, the point is the discussion with the student and the consensus between student and lecturer around competency. Using course lecturers as demonstrators to assess level of competence enhanced the student experience and provided the opportunity for students to practice communication skills. Using the oral assessment component to add value to the laboratory practical is in the early stages of development; however, it has been a positive experience for this group of students.

Future iterations of this study will include a survey of lecturers' findings regarding the oral assessment component, the value of which seems to be the immediate feedback it offers for students. It could also be redesigned so that students can see categories of competency, for example: observational skills, communication skills, and quality of conceptual explanation. Further improvements could also include quantitative data on the student performance on a test of conceptual knowledge. This study could also be made more robust by determining what proportion of students continued with their chemistry study and what impact this experience in the laboratory had in shaping their first impressions of chemistry.

It would also be interesting to examine what other variables might affect student attitudes and learning in the laboratory, such as confidence level prior to completing the laboratory session or age. The data also needs to be expanded across several iterations of the implementation to demonstrate reproducibility. Finally, incorporating changes in pedagogy to address the needs of a changing student cohort and shifting the emphasis from assessment for grades to assessment for learning have the potential to enhance the introductory chemistry laboratory experience.

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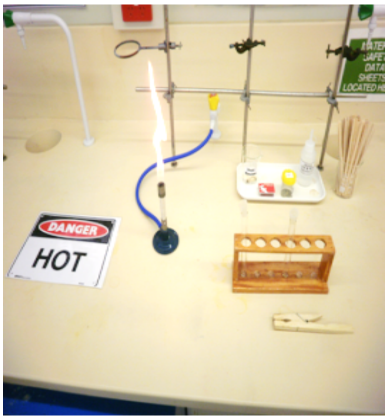
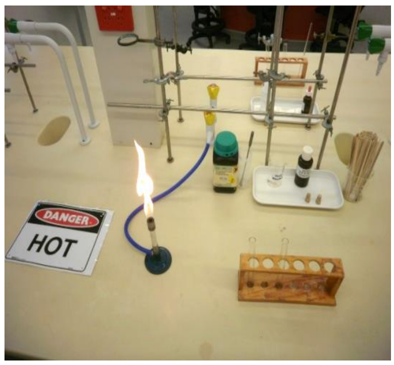
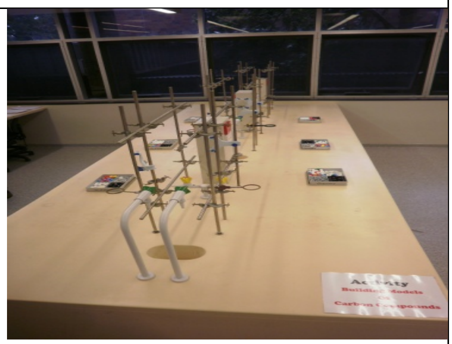
Appendix 1. Educational Analysis: Table of Intended Learning Outcomes

Theoretical and Conceptual Knowledge		
Learning Outcomes	**Process**	**Indicators**
What will students learn?	***How will students learn it?***	***How will staff and students know that the students have achieved the learning outcomes?***
1) There are different Classes of chemical reaction.	*By completing the five experimental setups and noting the different types of products*	*The demonstrator will check the balanced chemical equations and ask student to describe different types of reactions.*
2) The products of a reaction can be collected and analysed.	*By collecting the gasses which are produced and carrying out the appropriate test*	*If the wrong test is used the student will not get a result and then the demonstrator will be able to discuss the options with the student. Student will be asked about experimental techniques when collecting gases.*
3) The reaction can be accurately recorded by using chemical equations.	*Using their knowledge of chemical formulae to write and balance the equations describing the reactions.*	*The student can check with other team members and then the demonstrator will also check all equations. Student will be asked why it is important to make accurate observations.*
4) The difference between a physical change and a chemical change.	*The reactions will produce new products and therefore are all chemical changes*	*The students will indicate the type of change in the workbook. This can be discussed amongst team members. Student can be asked to give examples of a physical or chemical change to indicate understanding*
5) The difference between exothermic/endothermic.	*Holding the different solutions in their hands will indicate heat given off or heat taken in.*	*Accurate recording in the workbook, discussion with teammates and demonstrator. Student to be asked what is causing the temperature change.*
6) There are different tests for the presence of a gas.	*By collecting the gasses which are produced and carrying out the appropriate test*	*If the wrong test is used the student will not get a result and then the demonstrator will be able to discuss the options with the student.*
7) Which gas is the most flammable?	*By comparing the volume of gas produced, noise produced or reigniting of the lighted splint*	*The student can check with other team members and discuss with the demonstrator. What makes some gases more flammable than others?*
8) What does a precipitate look like?	*By making and observing the precipitate,*	*The student will record the details in the workbook to be checked demonstrator. Can the student name any other precipitates?*
9) Indicator paper is a tool which can be used to determine acidity.	*Observation of the indicator paper changing colour as the acid and the base react*	*The student will observe a colour change as the pH changes and then accurately record the pH in the table to be checked by the demonstrator.*
10) Acids and bases can neutralise each other	*The indicator paper will change colour to show the pH changing.*	*The student records colour change and accurately records pH in the notes to be checked by the demonstrator. Student will be able to explain the cause of colour change.*
11) Connecting conceptual chemistry to practical application	*Reactions can be performed in a test tube to observe the formation of products.*	*Confirming the products of reactions and where those products have come from.*
12) Integrating learning material from lectures to laboratory	*Different substances have different properties, react differently and there are different classes of reactions.*	*Confirming the products of reactions and why those products are formed.*
13) Linking accurate observations made with correct recording	*Writing formula and balancing equations is an important way of recording chemical reactions.*	*The student is able to accurately record the products of the reaction observed. Why accurate observation and recording are needed?*

Scientific and Practical Skills		
Learning Outcomes	**Process**	**Indicators**
What will students learn?	***How will students learn it?***	***How will staff and students know that the students have achieved the learning outcomes?***
1) Observing and recording using appropriate scientific language	*Writing and balancing chemical equations*	*Student is able to describe the reaction and procedure to the demonstrator.*
2) The importance of scientific communication	*Interaction and discussion with the demonstrator and team*	*The student is able to respond to questions from the demonstrator in a clear manner using the appropriate level of scientific language.*
3) Manipulating chemicals to cause a reaction. Manual Dexterity.	*Adding chemicals together can cause a reaction*	*Displays care and appropriate techniques when adding substances. How do you feel your technique affects the results? How would you rate your skill?*
4) Collecting and analysing the products of a reaction	*Collecting the products of a reaction requires handling skills Testing for the presences of Hydrogen and Oxygen requires different techniques*	*Is able to manipulate the equipment. Student can assess level of manual dexterity Student can describe the different tests and how to perform the test.*
6) Recording observations using chemical equations.	*Formulae and equations actually describe a reaction*	*Accurately records observations.*
7) Manipulation and safe handling of equipment	*Being able to collect the gas is a skill requiring some manipulation of equipment*	*Is able to demonstrate correct procedure for collecting gas and explain why it is used.*
8) Navigating a busy laboratory safely	*Being able to move around the laboratory without causing any congestion and being aware of other students.*	*Navigates the laboratory setting safely.*
9) Using personal protective equipment correctly	*Making sure that glasses are always on and the lab coat is securely fastened.*	*Maintains the use of PPE and can identify physical and chemical hazards in the laboratory.*

Appendix 2. Technical Notes.

STATION NO.	EXPERIMENT	MATERIALS	SET-UP
1	**Metal + acid**	• 2M HCl (dispensing bottle) • Magnesium ribbon pieces in a vial (~50 – 5mm) • Test tubes (standard) (x2) • Test tube rack • Corks (corks in the store) (x2) • Tapers • Test tube holder (not needed but just in case) • Matches • Beaker (for "dead matches" and tapers) • Bunsen	
2	**Carbonate + acid**	• $CaCO_3$ (solid chemical) + spatula • 2M HCl (dispensing bottle) • Limewater (saturated in Schott bottles) • Test tubes (standard) (x3) • Gas collection tube	
3	**Precipitation**	• Silver nitrate solution (dropper bottles) • 0.05M Sodium chloride solution (dispensing bottles) • Test tubes (standard) (x2) • Test tube rack • Glass stir rod	
4	**Decomposition (need fresh test tubes)**	• 3-5% Hydrogen peroxide (dispensing black bottles) • Manganese dioxide (solid chemical) + spatula • Test tubes (standard) (x2) • Corks (corks in the store) • Tapers • Matches • Beaker (for "dead matches" and tapers) • Bunsen (to light taper…good effect)	

5	**Neutralisation Properties and Reactions of Acids and Bases**	• 0.2 M HCl (dispensing bottles) • 0.2 M NaOH (dispensing bottles) • Conical flasks (50mL) • Measuring cylinder (10mL) • Glass rod stirrer • Universal Indicator paper (rolls) • Wash bottle • Beaker ("Used paper strips")	 
6	**Exothermic and Endothermic (need fresh test tubes)**	• NH_4NO_3 (solid chemical) + spatula • $CaCl_2$ anhydrous (solid chemical) + spatula • Test tubes (standard) (x2) • Test tube rack • Glass stir rod • Wash bottle	
Activity	**Building models of Carbon Compounds**	• Model kits (x6) 	
PPE		• Lab coats (S, M, L, XL) • Disposable gloves (S, M, L) optional • Glasses • Covered shoes	

Appendix 3. Student Laboratory Workbook Excerpt

Aim of the LABORATORY ACTIVITY

The aim of this laboratory activity is to observe and record a series of reactions. Also to identify the products of the reaction and determine whether a physical or chemical change has taken place.

This laboratory session consists of six experimental set ups at six stations around the laboratory and one modeling kit activity. Each task should be completed in 12-15 minutes.

The aim Experiments 1-6 is to:

- Determine whether each change is physical or chemical.
- Make observations and record what happens in the reaction.
- Write balanced equations for the reactions.
- Test for and then identify one of the products of the reaction.
- Explain to your demonstrator what is happening in one of the reactions.

Important Note:

Each experiment will be set up at a different station around the lab.

Working in groups of up to 3 you will move from station to station and complete each experiment or activity.

In every case, make sure you note down what you observe about each substance both before, and after, you carry out the experiment.

Please ensure that you tidy each workstation as you go and clean the equipment where necessary. The group following you should find each work station in good order.

Experiment 1:	Metal + Acid

Fill a test tube to about 3 cm depth with 2M hydrochloric acid.
Note the temperature of the liquid by touching the outside of the test tube.
Add one small piece of magnesium ribbon to the acid.
Observe what happens and note any temperature changes.

Part A: Observations
Note the temperature of the liquid before the reaction by touching the test tube and then describe what happens in the reaction.

Was there a change in temperature of the test tube?

Describe what you see in the test tube after the reaction.

Is this a physical or chemical change?

Give a reason for your answer.

Part B: Products of the reaction
Fill a test tube to about 3 cm depth with 2M hydrochloric acid.
Add one small piece of magnesium ribbon to the acid. Stopper the test tube to trap the gas. Wait until the reaction stops. Remove the stopper and place a lighted splint over the opening of the test tube to test for the presence of a gas

Observations:
Describe what happens when you place the lighted splint over the test tube opening.

***Write the balanced equation for the reaction.* (2 MARKS)**

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Experiment 2:	Acid + Carbonate

Place some solid $CaCO_3$ into a test tube to about 1 cm.
Add a small amount of 2 M HCl (about 2 cm).

Part A: Observations
Describe the appearance of both the $CaCO_3$ and the acid before reaction.

Note the temperature of the liquid before, and after the reaction by touching the test tube.
Describe the reaction and note any temperature change.

Describe what you see in the test tube after the reaction. Is this a physical or chemical change?

Part B: Products of the reaction
Place some solid $CaCO_3$ into a test tube to about 1cm.
Add a small amount of 2 M HCl.
Quickly stopper the tube with a glass collecting tube and place the other end of the tube into a test tube containing limewater to a depth of 3 cm.

Observations:
Describe what happens to the limewater.

***Write the balanced equation for the reaction.* (2 MARKS)**