International Journal of Science Education

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsed20

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Published online: 16 Jun 2015.

International Journal of Science Education, 2015
http://dx.doi.org/10.1080/09500693.2015.1052585

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Student experience surveys have become increasingly popular to probe various aspects of processes and outcomes in higher education, such as measuring student perceptions of the learning environment and identifying aspects that could be improved. This paper reports on a particular survey for evaluating individual experiments that has been developed over some 15 years as part of a large national Australian study pertaining to the area of undergraduate laboratories—Advancing Science by Enhancing Learning in the Laboratory. This paper reports on the development of the survey instrument and the evaluation of the survey using student responses to experiments from different institutions in Australia, New Zealand and the USA. A total of 3153 student responses have been analysed using factor analysis. Three factors, *motivation*, *assessment* and *resources*, have been identified as contributing to improved student attitudes to laboratory activities. A central focus of the survey is to provide feedback to practitioners to iteratively improve experiments. Implications for practitioners and researchers are also discussed.

Keywords: *Laboratory learning; Student practicals; Student engagement; Undergraduate education; Student experience surveys*

Introduction

Laboratory activities have long been seen as important components of science courses (Bennett, 2000; Boud, Dunn, & Hegarty-Hazel, 1986; Johnstone & Al-Shuaili, 2001; Psillos & Niedderer, 2002). Deters (2005) found that they are often the most popular element of courses and they have also been shown to stimulate and motivate students to learn more about science (Hofstein & Lunetta, 2004). Student engagement in laboratory courses has been shown to positively impact achievement in science (Lee, Lai, Yu, & Lin, 2012; Secker & Lissitz, 1999) and indeed, most researchers agree that the laboratory experience consistently ranks highly as a contributing factor towards students' interest and attitudes to their science courses (Hanif, Sneddon, Al-Ahmadi, & Reid, 2009; Osbourne, Simon, & Collins, 2003). Indeed, the laboratory experience can define a student's experience in the sciences and, if done poorly, can be the major contributing factor in causing students to disengage from the subject area (Rice, Thomas, & O'Toole, 2009). The challenge therefore remains to provide students with laboratory programmes that are relevant, engaging and effective in enhancing learning outcomes.

In a typical Australian university science curriculum, students are expected to spend about one-third to one-half of their instructional time in laboratory work (Royal Australian Chemical Institute, 2005; Rayner, Familiari, Blansby, Young, & Burke da Silva, 2012; Sharma, Mills, Mendez, & Pollard, 2005). So it is imperative that the opportunities afforded by this learning environment are realised. This potential is seldom achieved (Hegarty-Hazel, 1990; Hofstein & Lunetta, 2004; Reid & Shah, 2007). For instance, some laboratory activities have been shown to result in working memory overload and/or cognitive disengagement (Johnstone, 1997). Poorly designed and implemented laboratory exercises can engender a 'going through the motions' approach in the laboratory (Johnstone & Al-Shuaili, 2001), leading to a perception that laboratory activities consist of simply following dull, uninteresting recipes

(Del Carlo & Bodner, 2004). This environment does little to motivate students, or to support their learning.

There have been many previous studies, and previous instruments, that have been designed to probe different facets of the undergraduate laboratory. The role of the teaching assistant (TA), or demonstrator, is often seen as pivotal to the student experience and the perceived importance of the different roles of the TA has been investigated from both TA and student perspectives (Herrington & Nakhleh, 2003). Student interest in the laboratory has been investigated (Beck, Butler, & Burke da Silva, 2014), as has student engagement (Sadler, Puig, & Trutschel, 2011). A laboratory experience that is relevant to the real world is often declared to be motivating for students (Prince & Felder, 2006), even if relevance is not well-defined in science education (Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). The development of teamwork skills and communication skills are two attributes seen to be necessary for science graduates, and the development of these attributes is often consigned to the laboratory environment. As a consequence, they are often built explicitly into the laboratory process by requiring students to work in groups and to communicate their findings to teachers or peers (Boyer, 2003; Hofstein & Mamlok-Naaman, 2007). The concept and value of 'inquiry' in laboratories have been the subject of extensive discussion over several decades. Inquiry is generally (Abd-El-Khalick et al., 2004; Brownell, Kloser, Fukami, & Shavelson, 2012; Myers & Burgess, 2003), though not always (Kirschner, Sweller, & Clark, 2006; Settlage, 2007), seen as a good thing to aspire to in the laboratory and there are many instruments, rubrics and methods to evaluate both levels and nature of inquiry (Bruck, Bretz, & Towns, 2009; Fay, Grove, Towns, & Bretz, 2007; Volkmann & Abell, 2003). However, demonstrating a link between the level of inquiry and student learning is notoriously difficult to measure (Bodner, MacIsaac, & White, 1999). Indeed, the whole topic of assessment in the laboratory has been the subject of many investigations (Bretz, 2012), including ways of exploring what the students have learned.

Many of the instruments above provide valuable information about one or more aspects of the laboratory experience. However, few surveys explore the overall laboratory experience across multiple dimensions. Even the few multidimensional surveys that are available (Del Carlo, Mazzaro, & Page, 2006; Fraser & McRobbie, 1995; Fraser, McRobbie, & Giddings, 1993) do not try to capture the students' overall experience. To our knowledge, there is no instrument in the literature that can address the question that interests us, which is:

> Immediately following the laboratory session, what are the underlying factors that dictate a students' own perception of their overall laboratory experience?

In essence, we seek to discover what makes a student look forward to the next laboratory session, rather than feeling antipathy, ambivalence or anxiety. All of the elements above—interest, engagement, TAs, assessment, learning, group work, level of inquiry—may play a role in a positive experience of the laboratory. We seek to test the factors that are important to the immediate overall experience for the students. More importantly, we want to be able to provide a means by which a laboratory educator can make a simple assessment of an experiment and use the information to improve the laboratory experience for the students.

Over the past 15 years, the Advancing Science by Enhancing Learning in the Laboratory (ASELL) project has developed a suite of survey instruments to explore the student laboratory experience (see Yeung et al., 2011 for a description of ASELL) and to provide student-centred data in support of laboratory education. The ASELL Student Laboratory Experience (ASLE) survey is the instrument that we have developed and tested over the past 10 years, starting in physical chemistry, then including all of chemistry and now into other areas of science (biology and physics). The ASLE survey instrument is aimed at evaluating an individual laboratory exercise.

The aims of this paper are to describe (i) the conceptual construction and evolution of the ASLE survey for ascertaining student experiences of individual experiments, (ii) evaluation of the survey and (iii) implications for teaching practitioners and for research.

Methodology

Theoretical Framework

This paper utilises practitioner research or action research (McWilliam, 2004) to explain the evolution of the ASLE survey and its connection to a teaching development initiative in undergraduate science laboratories. Our project has practitioner research projects where improvements and tools are used at a very local level—with individual experiments in laboratory programmes—for implementing change and improving student learning in an iterative manner (Krockover, Adams, Eichinger, Nakhleh, & Shepardson, 2001; Krockover, Shepardson, Adams, Eichinger, & Nakhleh, 2002). Practitioner research embeds commitment to 'cycles' of improvement, and to reflection during and between each phase in the cycles. The study methods comprise participant observation, surveying, reflections and an extensive consultative process within and across the communities. Together with the local level practitioner research, we seek to contribute to global understandings on learning in science laboratories. Consequently, our overall research design is best described by the design-based research approach (Sharma & McShane, 2008). Findings from extant literature inform the local practitioner research cycles and vice versa. This paper garners understandings from many local practitioner research efforts in an attempt to advance global understandings.

Our focus is to obtain student assessment of their laboratory experience using the ASLE survey, with the intent to provide feedback to academics on how to improve individual experiments. A sound basis for the survey design includes giving due consideration to content and face validity. Content validity reflects appropriate coverage of the laboratory experience; in our case it is the breadth of skills and understandings associated with student experiences of laboratory experiments. Face validity pertains to whether the survey measures what it states that it is measuring. One way of ensuring content validity is by the use of the survey across various contexts and institutions and a way of ensuring face validity is by the critique and perusal of the survey by experts in the field. Both benefit through using a Delphi type approach (Dalkey & Helmer, 1963; Hasson, Keeney, & McKenna, 2000; Streveler, Olds, Miller, & Nelson, 2003) where the survey is iteratively examined and modified via consultation with experts until it settles on a final version.

Development of the Survey

Three Phases of Development

First phase—scoping questions: The construction of the survey began in 2000 with the funding of an Australian national grant on improving laboratories in the domain of physical chemistry. From 2000 to 2002, a framework for evaluating and improving individual experiments was developed. The framework involved three steps: (1) experiential workshops in which peers and students did experiments that had been submitted from different institutions and provided feedback (Barrie, Buntine, Jamie, & Kable, 2001); (2) the experiments were improved, based on the workshop feedback and (3) the improved experiments were evaluated by students in the home institution. A series of open-ended questions were developed for evaluating the individual experiments in step (3) (Buntine, Kable, & Metha, 2004). The questions were designed to capture the breadth of skills and understandings associated with student experiences of laboratory experiments from the perspective of academics embedded in undergraduate labs. Pertinent to the design of the questions were conversations between educationalists and scientists resulting in questions that had a sound educational basis.

Several of the experiments that were assessed at the workshops were improved by workshop participants and re-run within normal laboratory programmes in home institutions where they were evaluated using the open-ended questions. Fourteen different experiments from 10 Australian and New Zealand institutions went through this process generating >300 student responses to the open-ended questions. The critical element of the dataset was the diverse set of experiments from different local contexts. There were sufficient data from the open-ended responses to generate Likert scale items.

Second phase—development of Likert scale items: As the discipline base grew to include all of chemistry, the opportunity arose for a statistical approach. We converted findings from the open-ended questions into a set of Likert scale items and for these to be supplemented by a smaller set of open-ended questions (Table 1). The key themes from the open-ended questions and student responses were extracted and condensed into Likert items. These Likert items were aligned with research literature describing the benefits that can accrue from inquiry-based laboratory exercises (Palmer, 2009) and teamwork (Johnstone & Al-Shuaili, 2001). The items were discussed within the project team and the wider community and refined iteratively. With each refinement the items were cross-checked with the themes from the open-ended responses from students to retain authenticity to the student experience. In order to prevent student survey overload, we limited the number of Likert items to 14.

Table 1. Likert scale and open-ended items in the ASLE instrument

Full item	Short name	Scale used
1. This [experiment] helped me to develop my data interpretation skills	Data interpretation skills	a
2. This [experiment] helped me to develop my laboratory skills	Laboratory skills	a
3. I found this to be an interesting [experiment]	Interest	a
4. It was clear to me how this [laboratory exercise] would be assessed	Clear assessment	a
5. It was clear to me what I was expected to learn from completing this [experiment]	Clear learning expectations	a
6. Completing this experiment has increased my understanding of [discipline]	Increased understanding	a
7. Sufficient background information, of an appropriate standard, is provided in the introduction	Background material	a
8. The [demonstrators] offered effective supervision and guidance	Demonstrators	a
9. The [experimental procedure] was clearly explained in the lab manual or notes	Laboratory notes	a
10. I can see the relevance of this [experiment] to my [discipline] studies	Relevance	a
11. Working in a team to complete this [experiment] was beneficial	Teamwork	a
12. The [experiment] provided me with the opportunity to take responsibility for my own learning	Own learning	a
13. I found that the time available to complete this [experiment] was	Time	b
14. Overall, as a learning experience, I would rate this [experiment] as	Overall	c
Open-ended questions		
15. Did you enjoy doing the experiment? Why or why not?		
16. What did you think was the main lesson to be learnt from the experiment?		
17. What aspects of the experiment did you find most enjoyable and interesting?		
18. What aspects of the experiment need improvement and what changes would you suggest?		
19. Please provide any additional comments on this experiment here		

Notes: Scales used: (a) A = 'strongly agree', B = 'agree', C = 'neither agree nor disagree', D = 'disagree', E = 'strongly disagree'; (b) A = 'way too much', B = 'too much', C = 'about right', D = 'not enough', E = 'nowhere near enough'; (c) A = 'excellent', B = 'good', C = 'average', D = 'poor', E = 'very poor'.

Words in square brackets could be changed to suit the laboratory, discipline or country context. The short name is used in the text to refer to items, which are responded to on the five-point scale indicated.

The Likert scale survey provides a more quantitative measure of the effect of changes to individual experiments on student experiences, while retaining some open-ended questions provided a qualitative assessment of the student experience and which items contributed to this experience and in what ways.

Third phase—roll out to ASELL in biology, physics and the USA: The extension of the project from the domain of chemistry to include the other enabling sciences of biology and physics was funded in 2009. A team of experienced educators from the three disciplines reviewed the instrument at that time and determined that the language and concepts in the survey were appropriate for students in the two new disciplines. At this time the word 'chemistry' was changed to reflect the widened scope of the experiments.

Data Collection

All data collection was undertaken under two regimes. During the evaluation and testing of the instrument (Phases 1 and 2 above), the surveys were conducted by a member of the ASELL team under the auspices of the University of Sydney Human Research Ethics Committee. In Phase 3, after the instrument had been finalised, the instrument required ethics approval from each home institution. In both situations, undergraduate students were given the instrument by their laboratory demonstrator (TA) towards the end of the laboratory session. The surveys were anonymous and voluntary; the only identifying feature was the experiment under evaluation, and the Unit of Study (course) undertaken by the student.

All statistical analyses were carried out using XLSTAT (Addinsoft).

Results—Evaluation of the survey

Properties of the Dataset

The dataset consists of 56 studies, surveyed across 19 institutions in 3 countries (Australia, New Zealand and the USA). Most of the experiments were at the First Year (Freshman) level (44), with 12 in upper-level classes. A total of 3153 students responded to the survey at an average of 56 responses for each experiment. We have not targeted a representative or a specific group of universities, nor the ability level of students in the classes. In this paper, we report on the performance of the survey on the dataset as whole.

The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy (Kaiser, 1970) was 0.92, which indicates that there is an adequate sample size for factor analysis (Dziuban & Shirkey, 1974). Bartlett's sphericity test (Bartlett, 1950) for correlations amongst the data provided $p < .001$ demonstrating the presence of correlations in the items (Dziuban & Shirkey, 1974). The statistics of the dataset as a whole are summarised in Table 2.

Factor Analysis

We performed an exploratory factor analysis, using principle component extraction and Varimax rotation (Kaiser, 1958). Item 14 was omitted because it is a summary item. Two items, 11 ('Teamwork') and 13 ('Time'), appeared as separate, non-correlating items, always loading by themselves with an eigenvalue >0.9. These items are

Table 2. Summary statistics of the dataset

Item	Value
Number of samples, N	3153
Number of experiments, N(exp)	56
Average responses per experiment	56
Number of different institutions, N(inst)	19
First year/freshman experiments	44
Upper-level experiments	12
KMO measure of sampling adequacy	0.92
Bartlett's sphericity test	$p < .001$

useful for the practitioner, but did not load systematically with the other items, indicating that they are associated somewhat differently from the other items to student experiences of laboratory experiments. Because they probe important aspects of the laboratory environment for the practitioner to consider, they have been retained in the discussion of results.

The analysis started by including only two factors, adding factors, one at a time, while monitoring the eigenvalues, λ, and factor loadings after Varimax rotation. While guided by the general rule of retaining factors with $\lambda \geq 1$, we sought the appropriate number of factors such that every variable (survey item) had a loading >0.5 (representing 25% correlation) with at least one factor. The minimum number of factors satisfying these conditions was three. The eigenvalues and factor loadings are shown in Table 3. The next largest eigenvalue was $\lambda = 0.72$.

The three factors include 6, 3 and 2 survey items, as shown in Table 3. All items fall clearly into a single factor with factor scores in the range 0.58–0.77. No significant cross-loadings were evident; all secondary loadings had eigenvalues that were at least 0.25 smaller than the dominant loading. However, there were a small number of minor cross-loadings with factor scores >0.32 (10% of variation), marked as 'X' in Table 3. These cross-loadings occur in sensible places and are discussed further below.

The dominant factor, with six items and the largest contribution to the variance, includes the items: *laboratory skills*, *data interpretation skills*, *interest*, *increased understanding of the subject*, *relevance to course* and *taking responsibility for own learning*. All of these items can be viewed as student-centred. *Interest*, *relevance*, *understanding* and *responsibility for own learning* are held responsible in several studies for motivating students (Frymier & Shulman, 1995; Ryan & Deci, 2000; Wigfield & Eccles, 2000), and so we call this factor ***motivators***.[1]

The second factor has two dominant items (*clear assessment* and *clear learning expectations*). These items are both concerned with ***assessment***, which is the term we use for this factor. There are also two minor cross-loading items (*increased understanding of subject* and *background information*).

The third factor includes *demonstrators*, *laboratory notes* and *background information*. These items are instructor-centred to the extent that the instructor is responsible for

Table 3. Factor analysis statistics

Item	Factors		
	Motivators	Assessment	Resources
Factor scores			
Data interpretation skills	0.667		
Laboratory skills	0.727		
Interest	0.686		
Responsibility for own learning	0.578		
Relevance to discipline	0.679		
Increased understanding	0.618	X	
Clear learning expectations	X	0.725	
Clear assessment		0.671	
Background material		X	0.633
Demonstrators			0.699
Laboratory notes			0.766
Statistical parameters on factors			
Eigenvalues	5.0	1.1	1.0
% variance	26.6	19.6	15.4
Cumulative % variance	26.6	47.2	62.6
Cronbach's α (total $\alpha = 0.87$)	0.86	0.71	0.69

Notes: Three true factors are identified. All items in these factors have loaded with $\lambda > 0.5$ into a single factor. Three small cross-loadings with $0.32 < \lambda < 0.5$ are evident, as marked by a cross. Loadings with $\lambda < 0.32$ have been omitted.

writing the laboratory notes, providing the background information and selecting and training the demonstrators or TAs. The role of these three items for the students in the laboratory is as a source of information for carrying out the experiment and so we call this factor ***resources***.

The difference between the analysis of a single experiment and the results of this large and diverse dataset contains useful information for the practitioner, as described below.

Analysis of the Summary Question

The summary item, Q14 ('Overall experience'), was designed to provide a single catch-all measure of the students' assessment of their overall laboratory learning experience. The responses to Item 14 for individual experiments demonstrate experiences that range from very positively skewed towards 'A: excellent' through skewed towards less satisfactory experiences. To explore the relationship between the three factors identified above and the overall experience we score the responses in two ways: (i) %positive – %negative responses, where positive A and B responses (see Table 1) were treated equally, as were negative D and E responses and (ii) scaling the extreme responses A and E as twice as strong responses as B and D. Approach

(i) provides a score from −100% to 100%, with no judgement about the 'value' of each response. Approach (ii) provides a score from −2 to 2, but relies on a value judgement that A/E and B/D are opposite but equally weighted, and that A and E are valued twice as much as B and D.

Both analyses gave very similar results with almost identical correlation coefficients. However, it was notable that the −2 to 2 scoring provided a better spread and separation of the scores at the high and low ends while the %positive − %negative score tended to bunch the data at the extremes. Therefore we only report the −2 to 2 scores herein.

One of the stated objectives of this work is to explore which factors and items correlate with the overall laboratory experience. A coarse measure of this correlation is to calculate the average score (using either scale above) for each survey item or factor for each experiment. This average is recorded as the score for each item/factor. Figure 1 shows graphs of the factor or item scores plotted against the score for the *overall laboratory experience* item for each experiment in the dataset. The correlation for the ***motivators*** factor is remarkably strong with $R^2 = 0.82$. The correlation for the other two factors, ***assessment*** and ***resources***, is weaker with $R^2 = 0.55$ and 0.50, respectively. There is essentially no correlation with the individual *teamwork* and *time* items ($R^2 = 0.00$ and 0.13, respectively).

The correlation between each of the items comprising the ***resources*** factor and the overall experience is shown in Figure 2. In this figure we have divided the data into quadrants. The dashed lines in the figure represent the average overall experience score (vertical line) and the average score for *demonstrators*, *lab notes* or *background material* (horizontal lines). The data points in blue indicate experiments for which the students' assessment of the item and overall experience is similar—both above average or both below average. The points in red and green represent experiments where the assessment of the item and overall experience is different. Specifically, there are many fewer experiments where the ***resources*** item is evaluated favourably with an unfavourable overall experience than the reverse. We consider these three items to show a threshold behaviour. This is also demonstrated by a distinct break in the regression line for points above and below an overall score of 1.0. The quality of the practical notes, or background information or demonstrators needs to reach an appropriate standard for a satisfactory student experience. However, further improving the quality of these items does not lead to much further improvement in the laboratory experience.

There is no significant 'threshold' effect evident in the correlation between any other items and the overall laboratory experience.

Discussion—Implications for teaching practitioners and for research

Laboratory learning is a cornerstone of most science degrees because it provides students with an opportunity to develop and practice the skills needed to become scientists. Most science academics value the laboratory experience, but few are accomplished in understanding the most appropriate approaches to build high-quality

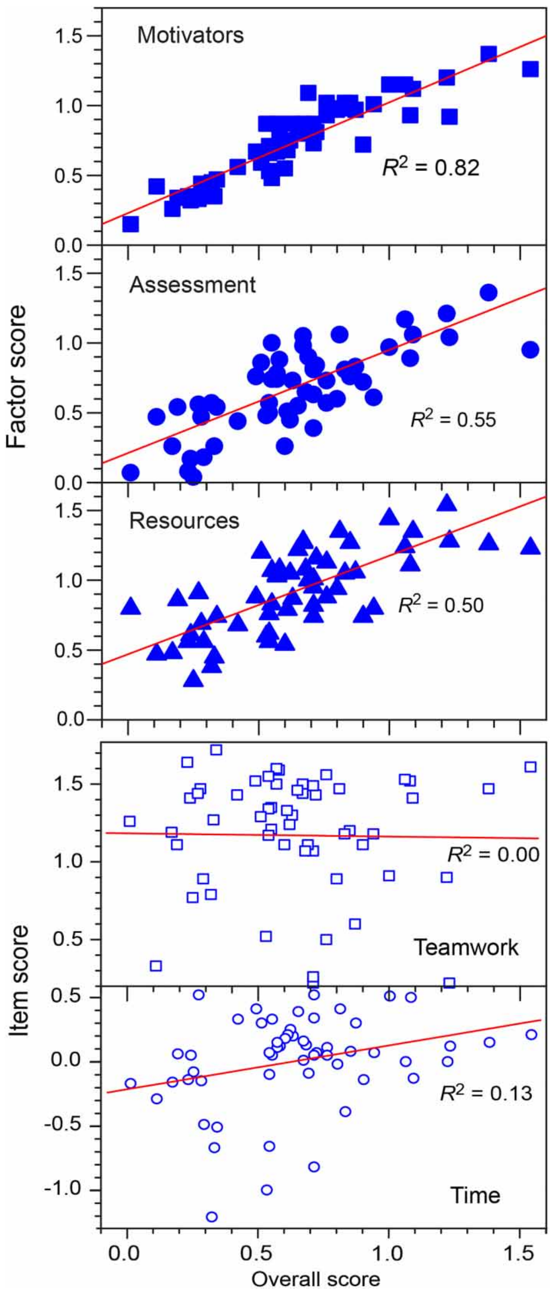

Figure 1. Factor or item scores plotted against the score for the *overall laboratory experience* item for each experiment in the dataset

learning experiences for their students. Many laboratory experiences have received considerable criticism for the lack of student learning that occurs in the laboratory (Arons, 1993; Hofstein & Lunetta, 1982; Novak, 1988; Rice et al., 2009). 'Expository'

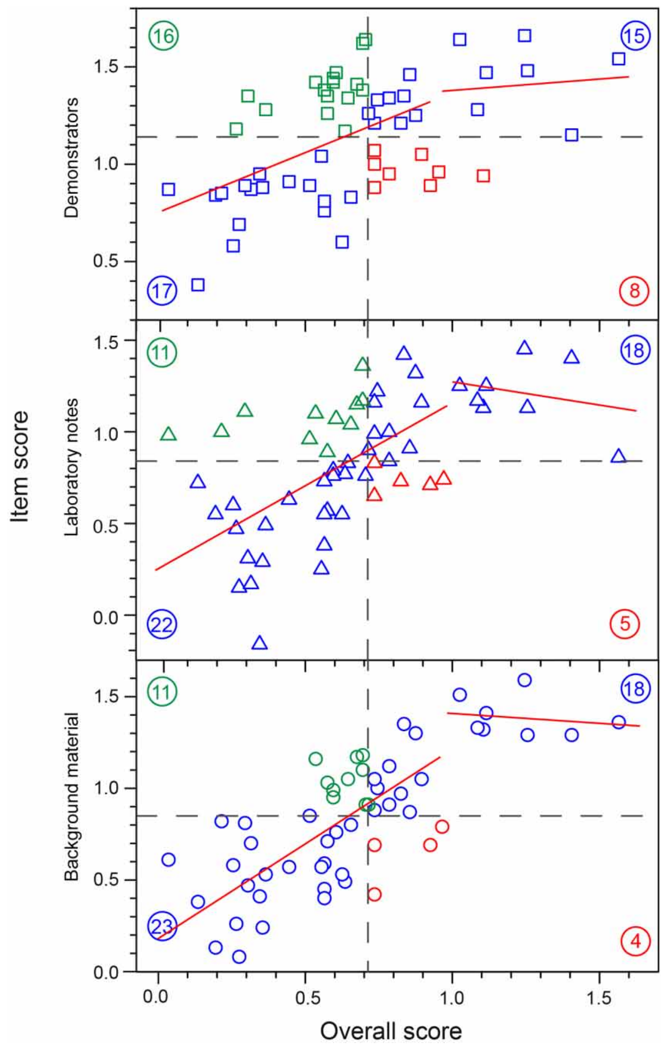

Figure 2. The correlation between each of the items comprising the ***resources*** factor – *background information, laboratory notes and demonstrators* – and the overall student assessment of their laboratory experience. A break in the regression line is evident at an overall score of 1.0, indicating that improvement in the overall laboratory experience no longer depends on resources once a certain standard is reached

or 'recipe' labs have been frequently criticised because they do not require students to think or make decisions, and do not develop deeper learning or complex skills (Domin, 1999, and references therein). At the other extreme, 'authentic inquiry' labs have been lauded for their engagement of students, development of research skills, critical thinking and problem-solving (Volkmann & Abell, 2003). However, other researchers have shown that expository labs are excellent at teaching fundamental laboratory skills such as manipulation of equipment—free from overarching concerns of problem-solving (Domin, 1999; Cummins, Green, & Elliott, 2004). Labs run on a purely inquiry model have had their critics as well—they are more expensive, more time-consuming for both staff and students, and there is a risk of confusing and alienating students who lack relevant experience and therefore feel 'out of control' (Deters, 2005).

Providing science academics with information about various aspects of their practicals as a tool to improve the quality of student learning experience was the aim of this project. We have found that there are some attributes that have more influence than others and other factors, even if done well, had little effect on the overall student experience.

Here, we examine further the individual items that comprise each of the three factors. Within the ***motivators*** factor, two items, *interest* and *responsibility for own learning*, stand out as having exceptionally strong individual correlations with students' rating of their overall laboratory experiences, as shown in Figure 3. Student interest

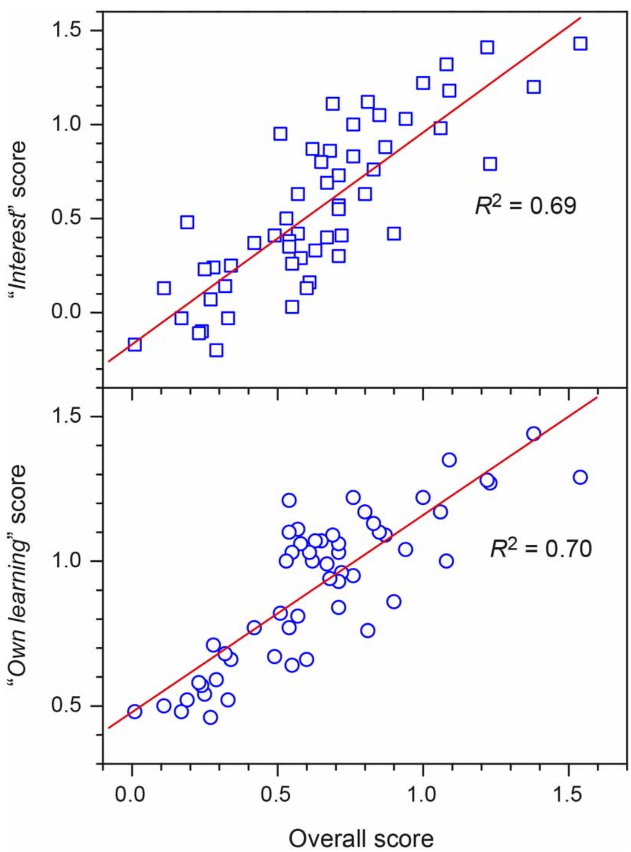

Figure 3. Within the ***motivators*** factor, two items, *interest* and *responsibility for own learning*, stand out as having exceptionally strong individual correlations with students' rating of their overall laboratory experiences

has a long history in the literature as being important for learning and engagement (Hidi & Renninger, 2006; Hidi, Renninger, & Krapp, 2004; Renninger & Hidi, 2002). While this item on the ASLE survey on its own does not probe the multifaceted nature of 'interest' extant in the literature (e.g. situational versus individual; triggered versus maintained), the results demonstrate unambiguously that creating student interest in an experiment is an important ingredient for a positive overall laboratory experience. Conversely, practicals that are focused primarily on skills development (as the main aim) may not provide enough interest to engage students in the learning process and consequently have limited value.

Inquiry-based approaches have been shown clearly to facilitate learning in undergraduate science laboratories (Beck et al., 2014) and, since 1985, the US National Science Foundation has promoted the enhancement of undergraduate science instruction, especially in laboratory courses (Tuss et al., 1998). 'Responsibility for own learning' is our proxy item for inquiry, or non-cookbook experiments. 'Relevance' is a well-established precept of educational psychology (Albanese & Mitchell, 1993), although Stuckey et al. (2013) reason that it is not as clearly defined in the science curriculum. Further, they argue that 'relevance' is often used synonymously with 'interest' or 'importance'. In the ASLE instrument we have explicitly separated *interest* and *relevance*. Although they end up in the same factor, different experiments can end up with quite different scores in these items. Simply telling students that they will need certain knowledge and skills in the future is not a particularly effective motivator (Prince & Felder, 2006).

The novel contribution that our work brings into the discussion on learning in laboratories is student acknowledgement that science-specific skills and understanding contribute to improved learning experiences, side-by-side with other facets such as 'interest' and 'responsibility for own learning' which are more widely discussed in research. We argue that 'lab skills', 'data interpretation skills' and 'increased understanding' of the discipline, when integrated, define the unique learning environment of the undergraduate laboratory in the enabling sciences. However, as commented above, these skills need to be balanced with the other items in the ***motivators*** factor, namely *interest*, *relevance* and *responsibility for own learning*. Without the ***motivators***, the laboratory experience can become primarily skills development, which is heavily criticised. Our survey provides a mechanism through which this balance can be struck. If experiments are evaluated using the ASLE survey, practitioners can gauge if individual experiments are balanced or not. In our perusal of literature we have not found any studies that provide this integrated aspect of the laboratory experience.

The items that comprise ***assessment*** correlate less with the overall learning experience than the items in ***motivators***. We do not assert that these items are unimportant in the laboratory environment—quite the opposite; clear assessment is crucial in all aspects of student learning. However, a poor laboratory exercise with clear assessment is still a poor laboratory exercise.

The items in the ***resources*** factor are most poorly correlated with the overall laboratory experience and display a threshold effect. While the poor correlation of 'practical notes' and 'background material' with the overall experience might not be surprising to many educators, the lack of correlation between the quality of the laboratory instructors and the overall experience is more surprising and warrants further discussion.

Previous studies have concluded that the laboratory instructor is the most important factor in student learning in the laboratory (Lazarowitz & Tamir, 1994; Pickering, 1988; White, 1996). However, the findings in this work suggest that the students' perceived quality of the instructors correlates poorly with their experience in the laboratory. The mantra that this project has adopted is that 'while poor demonstrators can ruin a good experiment, good demonstrators cannot rescue a poor one'. We speculate that when many students think of the important qualities for an effective laboratory teacher they consider knowledge-based qualities first, but they also consider affective domain qualities as important. For example, more than half of the students who responded to the questionnaire mentioned both knowledge and affective domain qualities in their descriptions of an effective lab teacher (Herrington & Nakhleh, 2003).

Finally, in a review article, Hofstein and Lunetta (2004) comment that the 'nature of science'-type surveys are applicable to whole courses and programmes and are not unique to laboratories. Here, the Science Laboratory Environment Inventory (SLEI) is notable. Developed by a group of Australians for use in schools, it has been utilised in several countries, and includes a multinational comparative study (Fraser & McRobbie, 1995; Fraser et al., 1993). Hofstein and Lunetta (2004) advocate the use of the SLEI as follows (p. 36):

> The science laboratory learning environment inventory could be used by teachers as one part of action research intended to examine the effects of a new laboratory teaching approach or strategy and as part of improving instruction. Researchers can also use this instrument for more summative-type studies in which they examine effects of different kinds of teaching in the laboratory on students' perceptions of the learning environment.

Our ASLE survey attempts to do the above for undergraduate science, and in the process has connected academics engaged in transforming learning in the laboratory and generated novel research findings.

Limitations of the Study

As a final comment, it is appropriate to reflect on the limitations in the present work. The study is obviously dominated by undergraduate experiments in Australian universities due to the geographical location of the authors. However, there are a few experiments from New Zealand and a couple from the USA in the dataset. The number of non-Australian university experiments is too small for any statistical conclusions, but these experiments appear qualitatively similar to the set of Australian studies. Nonetheless our conclusions should be taken in the context of Australian universities and students. Countries and cultures with different learning styles, teaching styles or different prior learning might produce different conclusions.

We pointed out in the analysis section that almost 80% of the studies were of First Year (General Chemistry) experiments. The conclusions are therefore dominated by the responses of students to such experiments and laboratories. There was no apparent or statistical difference between the First Year and Upper-level studies so all studies were aggregated. However, the set of Upper-level studies remains small here and the subject of First Year versus Upper-level laboratory experience is a topic of further research using the ASLE instrument.

Conclusion

Laboratory-based is a cornerstone of most science degrees because it provides students with an opportunity to develop many of the practical and critical thinking skills needed to become a scientist. Most educators instinctively value the laboratory experience, but few are accomplished in understanding what elements of a laboratory exercise actually contribute to effective student learning. This paper describes a student survey instrument that can help educators to iteratively improve experiments by helping to identify the extent to which student engagement is maximised.

Acknowledgements

We thank the students from three countries for participating in this study by voluntarily completing surveys. Collection of data described in this work was authorised by the Human Research Ethics Committee at the University of Sydney, project number 12-2005/2/8807.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Funding

We wish to thank the Australian government, for funding of this project over the past 15 years under the auspices of the Australian Learning and Teaching Council (project number CG9-1049) and progenitor bodies.

Note

1. We use *italic* font for survey item names and ***bold italic*** for factor names.

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