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Perceptions and Misconceptions about the Undergraduate Laboratory from Chemistry, Physics and Biology Academics

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Abstract

The undergraduate laboratory occupies a large fraction of science students' time. Over 3000 students were asked to rate their laboratory learning experience using 12 metrics. 362 academics were asked to predict which of these 12 aspects of the student experience would correlate with the overall laboratory learning experience. Responses from academics in biology, chemistry and physics departments, and from the USA and Australia, are statistically the same. However, the correlation between these staff predictions and student results is poor. The student results are consistent with extant educational research, but it appears that these findings are not reaching those who are responsible for developing undergraduate laboratory courses. There is a great need for educational research to be made more accessible for academics who are trained in scientific, but not in educational research.

Introduction

The laboratory has been an integral component in university science education for almost 130 years (Arzi, 1998; Black & Ogborn, 1979; Avi Hofstein & Mamlok-Naaman, 2007; Romey, 1968; Rowland, 1886; Schwab, 1962). At an address commemorating the 10th anniversary of Johns Hopkins University in 1886, Henry Rowland exhorted that "*If they (students) study the sciences, they must enter the laboratory, and stand face to face with nature…*" (Rowland, 1886). In the mid-20th century, Schwab (1962) and Romey (1968) reported how the laboratory environment provides a powerful learning environment. Building upon this, a growing body of research has shown that transforming undergraduate science laboratory programs from 'cookbook' labs to an inquiry-based learning environment provides a powerful framework for actively engaging students (Abrahams & Saglam, 2010; Volkmann & Abell, 2003). Rubrics have been developed to characterise the level of inquiry in laboratory exercises (Buck, Bretz, & Towns, 2008; Fay, Grove, Towns, & Bretz, 2007; Fayer, Zalud, Baron, Anderson, & Duggan, 2011), and it is well established that student perceptions of laboratories improve when active learning strategies in laboratories are adopted (Domin, 2007; Emenike, Danielson, & Bretz, 2011; Fayer et al., 2011; Kirkup, Pizzica, Waite, & Srinivasan, 2010). Indeed, it is widely accepted that engaging students in authentic processes of scientific enquiry, including both in the laboratory and post-laboratory writing (Moskovitz & Kellog, 2011), motivate and engage students of varying interest and abilities and from diverse backgrounds (Handelsman et al., 2004).

Good laboratory programs provide a learning environment where students can forge links between theoretical concepts and experimental observations (Hegarty-Hazel, 1990; A. Hofstein, Kipnis, & Abrahams, 2013). Learning goals that can be achieved through laboratory experiences include: subject matter mastery; improved scientific reasoning; an appreciation that experimental work is complex and can be ambiguous; and an enhanced understanding of how science works (Moore, 2006). High quality laboratory exercises that meet the above goals can teach a wide variety of scientific, professional and generic skills (Bennett & O'Neale, 1998; Boud, Dunn, & Hegarty-Hazel, 1986; Reid & Shah, 2007). Bennett and O'Neal (1998) note that high-quality laboratory courses should introduce students to a range of skills in a logical and coherent package, introduce students to investigative studies early in their studies and incorporate pre- and post-laboratory activities that actively engage students.

Given the widespread agreement in the literature of the value of learning in the laboratory (Coppola, 2011; A. Hofstein & Lunetta, 1982; A. Hofstein & Lunetta, 2004), it remains a fact that many undergraduate laboratory programs have been slow to adopt the outcomes of this research (Baker et al., 2014; Cech, 2003; Wood & Gentile, 2003). An on-going challenge in realising the adoption of research-informed teaching innovation lies with university recognition and reward structures that promote research innovation above that of teaching (Cech, 2003). Handelsman et al. (2004) have noted that one contributing factor to the slow pace of change is that many science teachers remain unaware of, distrust and/or feel intimidated by the research data. However, the issue is complex; a variety of inter-related factors contribute to the barriers to effective student learning. Interestingly, some evidence suggests that teacher attitudes towards the importance of practical work can improve with the introduction of investigative laboratory exercises (Abrahams & Saglam, 2010).

This paper explores practicing teacher expectations of what constitutes a 'good laboratory exercise' and compares these to the lived experience of students. Consequently, the research gives rise to four Research Questions:

1. Do teacher expectations of what constitutes a 'good laboratory exercise' differ between the science disciplines of biology, chemistry and physics?

2. Do teacher expectations vary in the distinct higher education environments of Australia and the United States?

3. How do teacher expectations compare to the lived experience of students?

4. Why are the predictions of teachers so misaligned with student experiences?

The implications for teaching practitioners and their professional development are discussed in the context of the findings of this study.

Methods

This study utilises the practitioner-based research approach described by McWilliam (2004) to explore teacher and student attitudes towards science laboratory exercises. We adopt quantitative methods, based upon a survey methodology and statistical approaches, to explore teacher and student attitudes to the question of what constitutes a 'good laboratory exercise'.

Instruments

Distinct survey instruments for staff and students were employed, and these are each described below.

The Student Survey: The research was carried out using instruments developed and tested under the auspices of the *Advancing Science by Enhancing Learning in the Laboratory (ASELL)* project (Barrie et al., 2015; Yeung et al., 2011), and its progenitors (Buntine et al., 2007), which has been operating in Australia for over 18 years. The *ASELL Student Laboratory Experience (ASLE)* instrument (Table 1; see Supplementary Material for the actual instrument) was developed to examine student self-assessment of their laboratory learning experience (Barrie et al., 2015). It does not assess learning gains, and is implemented immediately after the exercise is finished to ensure the hands-on, in-lab experience is fresh in the students' minds. The immediacy of the survey also divorces feedback on the laboratory experience from issues associated with assessment. Each student is asked to complete the ASLE instrument only once for any given exercise. However, any given student may have completed the ASLE questionnaire for multiple laboratory exercises. We are unable to comment on consistency of the student responses due to the anonymity of those providing the data. Nonetheless, the quality of the overall dataset has been extensively discussed in our previous publication (Barrie et al., 2015).

In an earlier publication (Barrie et al., 2015) we discuss the evolutionary development of the ALSE instrument with particular reference to the instrument's content and face validity and the quality and nature of the overall student response dataset. In this submission we use the student response data to compare to teacher attitudes.

The ASLE student survey implementation, its use in student self-assessment of the laboratory experience, and use by academic staff evaluating experiments, has been published several times. Read and Kable (2007) reported an educational analysis of an undergraduate thermochemistry experiment. Crisp et al. (2011) used the ASLE survey instrument to explore an apparent disconnect between teacher and student perceptions of the educational value of an experiment utilising polarimetry to determine sugar concentrations in aqueous solution. Bhathal, Sharma and Mendez (2010) reported using this instrument to explore educational aspects of an undergraduate physics experiment, while Southam and co-workers (2013) explored the impact on student education perceptions of an organic synthesis exercise that was conducted at differing times throughout a semester-long laboratory program. Burgess, Yeung and Sharma (2015) describe an analysis of student learning experiences in an introductory chemistry program. These studies demonstrate the wide applicability of the ASLE instrument in assessing science laboratories.

Table 1: The *ASELL Student Laboratory Experience (*ASLE) instrument and how it is scored.

Full Item	Short Name	Scoring
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 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 team to complete this [experiment] was beneficial	Teamwork	(a)
12. The [experiment] provided me with the opportunity to take responsibility for my own	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.

In brief, the ASLE instrument uses 14 × 5-point Likert statements, plus 4 open-ended items for a qualitative evaluation of the activity. Of the Likert items, the first 12 use the standard "Strongly Agree" to "Strongly Disagree" measures. Question 13 probes whether the length of time for the experiment was appropriate. Question 14 asks the student about their overall assessment of the laboratory learning experience with a response range from "Outstanding" to "Very Poor". In all cases, the central response was intended to be neutral. The dataset used for this work comprises 3099 student responses, including 54 experiments from 20 universities that range in size from large research-intensive to smaller regional universities in Australia, New Zealand (collectively referred to as Australasia) and the USA.

A detailed discussion of the nature of the 54-experiment dataset has been previously published (Barrie et al., 2015), including a detailed statistical factor analysis that describes the nature of the dataset. Experiments span the range from being predominantly recipe driven (primarily at the First Year – or Freshman – level) through to being significantly open-ended investigations (mostly at the upper-class level). As previously mentioned, here we use the student data to compare to teacher attitudes.

The Academic Staff Survey comprises the same set of 12 statements as Q1-12 in the student survey (see Supplementary Material). During a series of conferences and department visits during 2009-2015, academic staff volunteers were asked to predict which of the 12 ASLE statements they expected to correlate with student perception of the overall laboratory learning experience. The academics' predictions were sought based upon their lived experiences as educators, in general, and before any data related to student attitudes were presented and discussed.

The 362 academic staff spanned biology, chemistry and physics in mostly the USA and Australia. Academic staff from more than 30 institutions participated in this project. Thirty-one of the academic staff respondents had senior administrative responsibilities, including Deans and Associate/Assistant Deans. Staff demographic details are presented in Table 2.

Table 2: Demographics of academic staff responses to staff survey.

	BIOL	CHEM	PHYS	DEAN	TOTAL
Australasia	60	73	50	27	210
USA	5	98	30	4	137
Europe	0	14	1	0	15
TOTAL	65	185	81	31	362

The respondents were regular members of academic staff, with duties ranging from teaching-focussed to research-focussed. They were not, generally, science education researchers. Indeed, respondents were asked whether they had heard of the ASELL project, and only those who indicated they were not aware of the project were included in this analysis.

Analysis

Academic staff were asked to choose which four of the provided 12 ASELL statements they expected to correlate strongly with overall student perception of their laboratory experience (the "Yes" response in the instrument), and which four statements would exhibit least correlation (the "No" response, see Supplementary Material). Staff were not asked to rank their responses. Therefore each "Yes" response was treated equally, as was each "No" response. In our initial analysis, we assigned a score of +1 for a "Yes" response and –1 to a "No" response and did not score blank responses. This provided a metric that ranged from +1, which represents that all staff considered the item to be positively correlated, to a score of –1, which represents an item where all staff predicted no, or little, correlation. However, in discussing these results in various seminars, it became clear that the score of –1 was confusing because of the association with a negative correlation coefficient, R, for which a value of –1 indicates a strong but negative correlation, rather than zero correlation, as intended. Therefore we applied a linear scale and offset (halve the range, and add 0.5) to produce a metric that ranged from 0 (prediction of no correlation) to 1 (prediction of strong correlation). Such a scale does not distort the distribution and does not change the relative statistics, and, in particular, cannot change the rank. The final range of 0 – 1 did enhance understanding of the metric.

Academic staff responses are compared to responses provided by over 3000 students predominately from Australia and the US, with a smaller number of student responses from New Zealand. Student responses related to a total of 54 distinct experimental exercises, of which 43 were undertaken at the Freshman/First Year level. 48 of the experiments were undertaken in Australian universities, and 49 of the experiments were part of undergraduate chemistry programs. Full experiment demographic details are reported in Table 3.

Table 3: Demographics of the various experiments and institutional contexts reported in this study.

Experiments:	
Total experiments	54
First Year	43
Upper years	11
Australian experiments	48
New Zealand experiments	2
USA experiments	4
Chemistry experiments	49
Physics experiments	5
Universities:	
Total universities	20
Australian universities	17
New Zealand universities	2
USA universities	1
Students:	
Total students	3099
Australian students	2772
New Zealand students	85
USA students	242

Results

In this study we concentrate on the ASLE *overall student experience* (Question 14, see Table 1) and how the other 12 items (also reported in Table 1) correlate with this self-assessment. Essentially, what we are examining is, for students who rate their laboratory experience highly, which other items are also rated highly, and vice versa. Without implying causality, we seek the items 1-12 that correlate most strongly with the evaluation of the overall laboratory learning experience. To evaluate the strength of agreement with each statement we analysed the data in two ways: *i)* by tallying the %(broad agreement) – %(broad disagreement) for each Likert item for every laboratory exercise, and *ii)* by scoring +2, +1, 0, –1, –2 for Strongly Agree through Strongly Disagree. For reasons explained previously (Barrie et al., 2015), we prefer the second approach, although the results are almost identical either way; the conclusions do not change.

Two such examples are compared in Figure 1, where the item on "*Interest*" is shown to correlate quite strongly with the overall experience across the 54 experiments ($R^2 = 0.69$), while the item on "*Teamwork*" correlates very poorly ($R^2 = 0.0$). These data have been previously reported (Barrie et al., 2015), albeit without any comparison of the correlations presented here. The correlation of the other 10 items lies between these two extremes. In the Supplementary Material we report, for the first time, the correlation between overall student attitudes to the 54 experiments with all 12 items in the ASLE student survey.

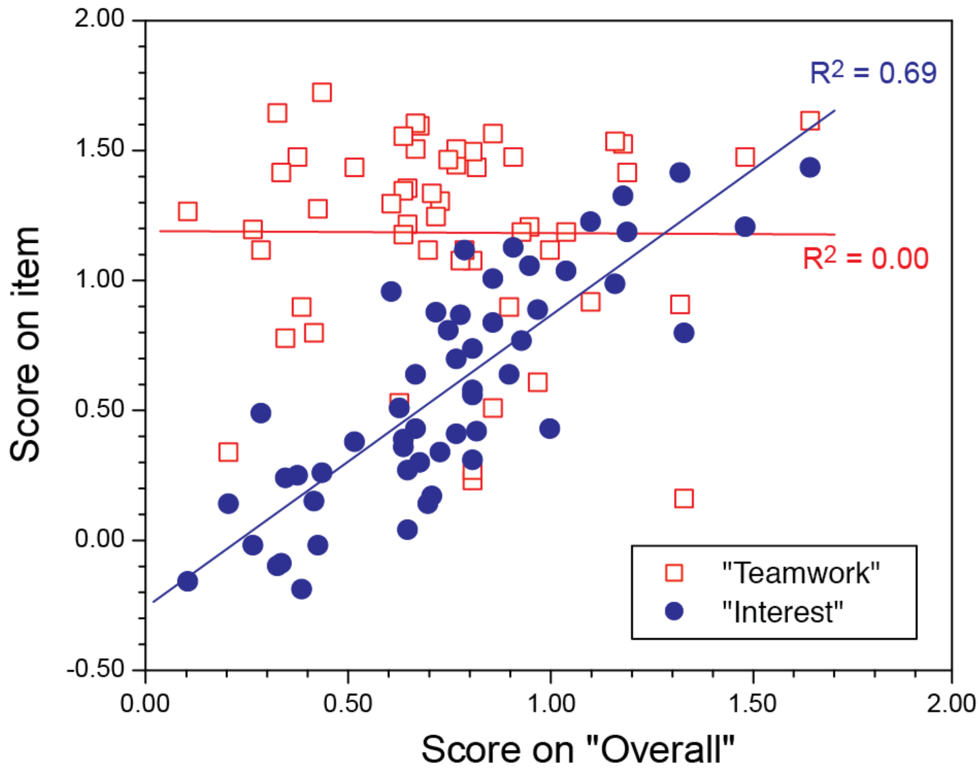

Figure 1: Example of correlation in students' responses to two of the 12 items in the ASLE survey: Item 3: "Interest", and Item 11: "Teamwork" to the students' overall assessment of the laboratory experience.

Research Question 1: ***Do teacher expectations of what constitutes a 'good laboratory exercise' differ between the science disciplines of biology, chemistry and physics?***

Figure 2A shows the average responses of academic teachers (excluding those with senior administrative responsibilities as their discipline expertise is not known) from biology, chemistry and physics plotted against the average for all teacher responses (error bars represent one standard error of the mean). The first point to note is that the responses cover most of the dynamic range of the metric; the lowest "all teacher" response (for "*teamwork"*) is 0.3, demonstrating that most academics did not believe that teamwork would correlate with the overall laboratory experience. The highest score was 0.8 (for "*interest*"), showing that a large proportion of teachers believed that the level of student interest in the experiment would correlate strongly. The other 10 scores are distributed across the whole range between these values.

The second very clear point to gain from these data is that there is no significant difference between the discipline cohorts. The data in Figure 2A attest that, at least for the three laboratory-intensive enabling science disciplines reported here (biology, chemistry and physics), the staff perception of the students' laboratory learning experience is remarkably uniform.

Research Question 2: ***Do teacher expectations vary in the distinct higher education environments of Australia and the United States?***

Figure 2B shows the same data, separated according to geography (USA or Australia; there are insufficient responses to draw any correlation conclusions from the European teachers). There is, again, no significant difference in the responses of each cohort (again, error bars represent one standard error of the mean). Although there are differences in tertiary science education between US and Australian universities (e.g. 4 *vs* 3-year degrees), perceptions of the scientist-teachers about laboratory education, as exemplified in this survey, are not different. Because of the clear similarity across regions and disciplines, we aggregate all into a single "teacher" response for comparison with student data.

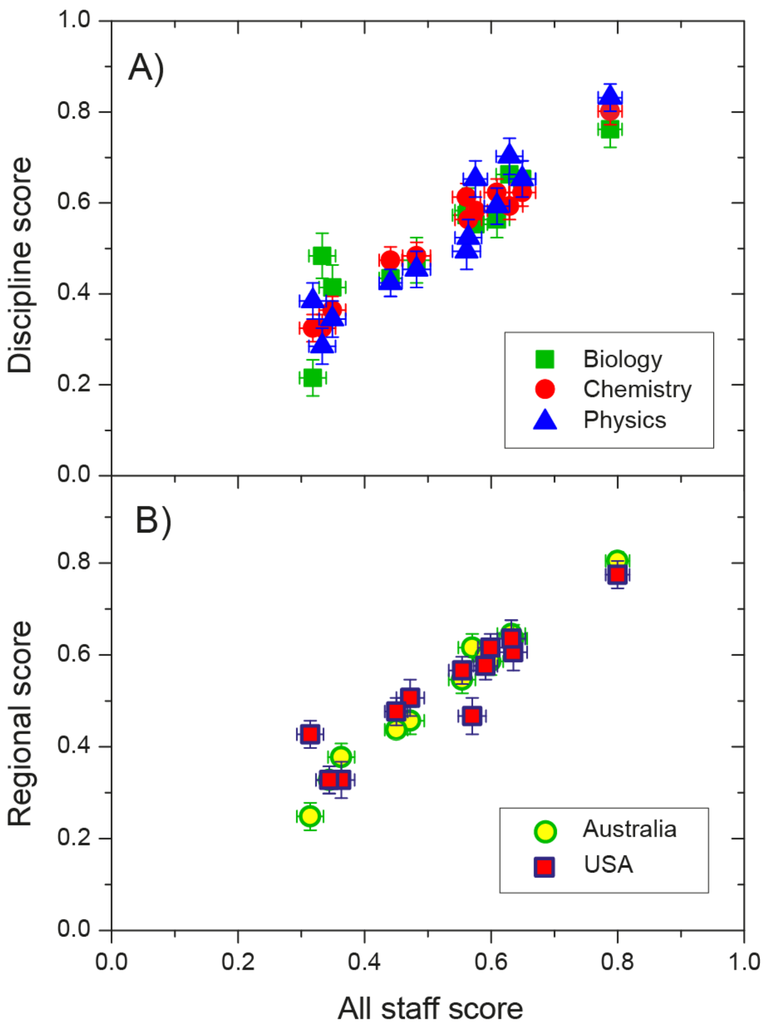

Figure 2: Reponses of academic staff separated according to A) discipline, and B) country.

Each data point represents the correlation between the overall teacher attitudes and those attitudes based upon discipline (top panel) or geography (lower panel) for the 12 items surveyed (see Supplementary Material for the staff survey instrument).

Research Question 3: ***How do teacher expectations compare to the lived experience of students?***

The metrics for analysing the academic staff and student responses were necessarily different and we therefore applied a rank analysis to further explore similarities and differences. Plots such as presented in Figure 1 were created for all student items, and the squared correlation coefficients (R^2) calculated (see Supplementary Material for all correlation plots). The items were ranked according to R^2, with results shown in Table 4. The four top-ranked items from the student surveys were: "*responsibility for own learning*", "*interest*", "*data interpretation skills*" and "*increased understanding*". The four highest-ranking items in the academic staff responses were "*interest*", "*demonstrators/teaching assistants*", "*relevance*", and "*practical notes*". A plot of the rank order of teacher versus student data is shown in Figure 3. Clearly, the data are scattered and there is no correlation between the two sets of ranks. This was quite a startling result to us, and was surprising to all audiences from whom we collected data.

Table 4: Rank order of academic staff and student responses

Student rank	Item	Academic rank
1	**The experiment provided me with the opportunity to take responsibility for my own learning**	**11**
2	I found this to be an interesting experiment.	1
3	**This experiment helped me to develop my data analysis/interpretation skills**	**10**
4	Completing this experiment has increased my understanding of [discipline][a]	5
5	It was clear to me what I was expected to learn from completing this experiment	7
6	The experimental procedure was clearly explained in the lab manual or notes.	4
7	I can see the relevance of this experiment to my [discipline][a)] studies.	3
8	It was clear to me how this laboratory exercise would be assessed.	8
9	This experiment helped me to develop my laboratory skills.	6
10	Sufficient background information, of an appropriate standard, is provided in the introduction	9
11	**The [demonstrators][b] offered effective supervision and guidance.**	**2**
12	Working in a team to complete this experiment was beneficial	12

[a][Discipline] = biology, chemistry or physics

[b]Replaced by "teaching assistants" in the USA

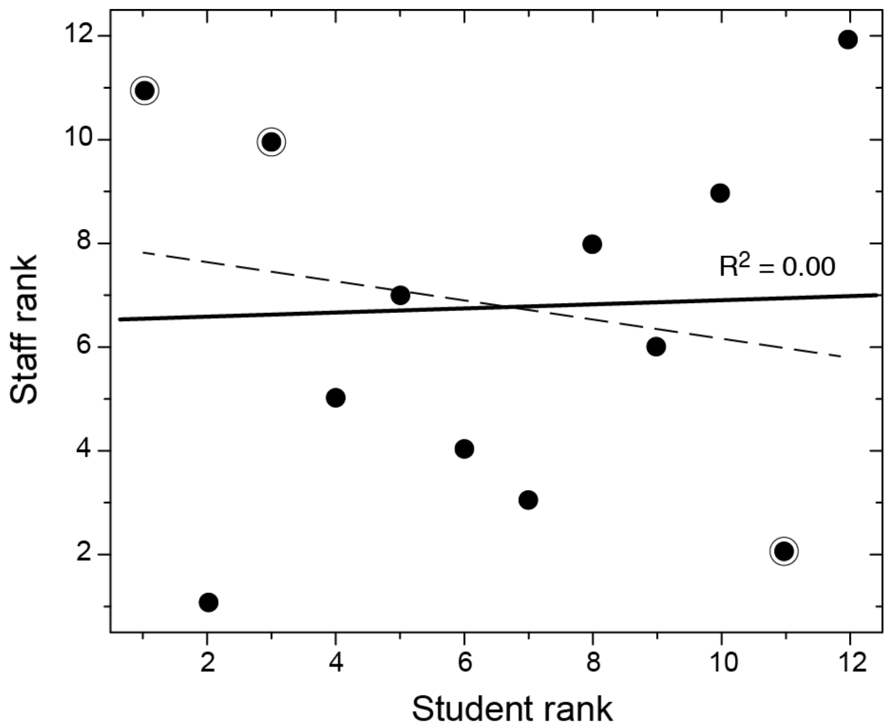

Figure 3: Ranked academic staff predictions plotted against rank order of student feedback.
Rank 1 indicates highest correlation between the item and the overall laboratory experience, while rank 12 indicates least correlation. The statistical correlation is zero. Circled points highlight items of greatest discrepancy as discussed in the text. The dashed line represents the correlation for the dataset of "Deans".

Discussion

The results reported above begs the fourth Research Question, "Why are the predictions of teachers so misaligned with student experiences?" Closer examination of Figure 3 and Table 4 reveals that three items stand out. These are highlighted in bold in Table 4 and circled in Figure 3. Teachers predicted a strong correlation for "*demonstrators*" ("*teaching assistants*" in the US), while this did not prove to correlate strongly in student responses. At the other end, teachers predicted "*responsibility for own learning*" and "*data analysis*" would not correlate well, but the students perceive these as important for their learning. If these three items are left out of Figure 3, the squared correlation coefficient increases to $R^2 = 0.65$, therefore we restrict our discussion below to these three discrepant items. Informal feedback from academics after presentations at ASELL staff development workshops inform this discussion. Our overarching conclusion from this feedback, coupled with the quantitative data analysis, and elaborated by the discussion below, is that when academic staff adopt a teacher-centred reference frame they become at risk of being disconnected from what motivates students to learn. One possible strategy to overcome this disconnect is to encourage teachers to recast their thinking into a student-centred framework.

"*Demonstrators*/*Teaching assistants*" (*T.A.*) and "*teamwork*" are the only two items that specifically probe the interpersonal interactions with others in the laboratory – with student colleagues in the *teamwork* item and with their instructors in the *T.A.* item. Academics anticipated correctly that the quality of the teamwork experience would not correlate strongly with the overall laboratory experience (Figure 1). However, they mistakenly believe that the quality of the instructor should strongly influence the overall laboratory learning experience. Students are more discerning than this. They can clearly separate the quality of the instructor from the quality of the laboratory experience. Some of the most engaging experiments have little reliance on T.A.s. In many of the poorer experiments (in terms of student ratings of 'overall learning experience' Question 14), T.A.s were thanked profusely, for example, from one of the most poorly rated exercises: "*Thank you to all the demonstrators in … lab. You are all very helpful.*" Our mantra, born from comments by many students, is that *'poor T.A.s can destroy a good experiment, but good T.A.s cannot rescue a poor one'.*

For students, "*Responsibility for own learning"* was the most highly correlating item with the overall laboratory experience across the 54 surveyed laboratory exercises ($R^2 = 0.70$; see Supplementary Material). Students were not told how to interpret this item; neither were academics. The item was designed to explore the influence of open-ended, or research-type experiments, versus "cookbook" experiments, but avoiding phrases like "discovery" or "inquiry" (Barrie et al., 2015). Experiments in the 54-exercise dataset spanned from being strongly recipe-driven to being overwhelmingly open-ended. Students rated the recipe-driven exercises poorly in terms of them taking responsibility for their own learning. Conversely, the more open-ended an experiment, the more highly students rated it in terms of their learning responsibility. Many of the experiments in this dataset are available at the ASELL website (www.asell.org).

Inquiry-based approaches have been shown to facilitate learning in undergraduate science laboratories (Beck, Butler, & Burke da Silva, 2014). Education researchers have long considered student *interest* to be important for learning and engagement (Hidi & Renninger, 2006). While this item on the survey does not probe the multifaceted nature of 'interest', the results clearly demonstrate that students finding an experiment interesting is an important ingredient for a positive overall laboratory experience.

Although beyond the scope of this paper, the *interest* item captures what laboratory educators have been telling us for years – that exploratory, research-based, open-ended experiments are very engaging and contribute strongly to a positive student laboratory experience. In academic staff interviews, this opinion was well-recognised. It was simply that the staff did not believe that students would recognise this in the survey. They were both right and wrong. *Responsibility for own learning* is a powerful motivator, and students <u>*do*</u> recognise it.

"Data interpretation skills" has a surprisingly strong correlation with the overall student experience, especially given the immediate post-laboratory timing of the survey administration. The types of experiments that scored well on this item required the students to process their observations or measurements in order to understand the underlying principles. The types of experiments that scored poorly are ones where the observation or measurement itself was the result. Research-type experiments, again, score very strongly here, and indeed, the process of analysing one's own data to learn about the underlying science underpins research by the academics themselves. It is well established that students find a well-designed laboratory that involves making meaningful choices and gaining control both stimulating and motivating (George, Wystrach, & Perkins, 1985; Paris & Turner, 1994).

Data analysis is intrinsically more challenging than simple observation, so these results are broadly consistent with motivational theory. The importance of the undergraduate research experience has been published in the science education literature many times (Buck et al., 2008;

Emenike et al., 2011; Fay et al., 2007; Fayer et al., 2011; A. Hofstein & Lunetta, 1982; A. Hofstein & Lunetta, 2004; Avi Hofstein & Mamlok-Naaman, 2007; Kirkup et al., 2010; Moskovitz & Kellog, 2011; Volkmann & Abell, 2003). Indeed, '*Data interpretation skills*' and '*Increased understanding*' of the discipline are part of what defines the unique learning environment of the undergraduate laboratory in the enabling sciences.

As a final observation, the correlation for the set of "Deans" (academics with senior administrative responsibilities) is shown as a dashed line in Figure 3, and we note that it has a negative slope! Due to the limited sample size of the Deans' responses (n=31), the difference between Deans' and academic staff predictions does not reach significance at $p = 0.05$. As such, the next comment must be considered carefully. Could it be that the further removed an academic is from the teaching laboratory, the less understanding they have of what makes for a good student learning experience?

The professional development challenge

The four items that correlate most strongly with the overall student laboratory experience are "*responsibility for own learning*", "*interest*", "*data analysis*" and "*increased understanding*". Only two of these were predicted by academics (see Table 4). These four items are broadly in agreement with the science education literature as discussed above, and therefore the student results would not be surprising to science education researchers. However, the demography of the respondents to our teacher survey are mostly coalface science academics; discipline experts, not science education experts. Handlesman et al. (2004) found that academics are largely unaware of the research findings in science education. If the academic staff from the >30 universities across Australasia and the USA are representative of the broader university community, then the results presented here make it clear that this remains a significant professional development challenge for universities.

All universities to our knowledge offer professional development in learning and teaching to their academic staff. In some, attendance at these courses is compulsory for new staff; at others it is optional. Many universities offer formal certificates, diplomas and degrees in higher education. The results presented here, however, show that these professional development programs, whether they are undertaken or not, are not having the desired impact for academic staff who are responsible for undergraduate laboratories.

But is it reasonable to expect researchers in one discipline (science) to also be experts in the research of another (education)? The language, literature, background, methodology and training are all different. Another approach is needed. If effective curriculum change is to be achieved, university science leaders need to embrace science education as a valued research discipline in their universities. These researchers will need to be discipline experts to teach at university, as well as education experts to achieve effective curriculum change. Tertiary education is undergoing a digital and on-line revolution. If these new technologies are to be used effectively in curricula, then the expertise in both the discipline and in education will be more valuable than ever.

Conclusions

Three hundred and sixty two US, European and Australasian academic staff were surveyed about what they consider constitutes a good undergraduate laboratory learning experience for students. Over 3000 US and Australian students were surveyed using the same questions. Biology, chemistry and physics academics were in complete agreement. However, the correlation between responses of the teachers and students is zero.

These results are confronting. Although the student responses would not be surprising to science education researchers, this work indicates that the findings of science education research are not making their way to the teachers who are responsible for undergraduate science teaching or curriculum design. This is a professional development challenge that science faculties and universities are not addressing satisfactorily.

A key factor that we identify in this study is that teacher expectations of what constitutes a ‘good laboratory experience’ are inconsistent with the lived experiences of students. We find that these staff misalignments are independent of both scientific discipline (biology, chemistry, physics) and geography (Australia, USA). Our results beg the question, ‘are teachers using their laboratory curriculum development time effectively?’, and suggest that greater emphasis on the professional development of academic staff, *beyond* the educational literature, is required.

Supplementary Material

The student and staff survey instruments are presented in Supplementary Information, together with correlations between ASLE Items 1-12 and Item 14.

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