The timing of an experiment in the laboratory program is crucial for the student laboratory experience: acylation of ferrocene as a case study

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An assessment of the acylation of ferrocene laboratory exercise across three successive years resulted in a significant fluctuation in student perception of the experiment. This perception was measured by collecting student responses to an instrument immediately after the experiment, which includes Likert and open-ended responses from the student. Students in all three years identified technical benefits from the experiment. In Years 1 and 3, students also recognised the benefits of improving their conceptual understanding of organic chemistry. However, in Year 2, where background knowledge became a critical and limiting factor, all perception of conceptual understanding as an experiment objective was lost, and only recognition of technical development remained. Analysis of these data also indicated that students who have enough time to complete the experiment also perceive a measure of responsibility for their own learning, whereas time-poor students have an over-reliance on the laboratory notes and demonstrators. Addressing concepts such as these may be the triggers required for time-poor experiments to garner a positive student experience and maximise both the conceptual and technical benefits of the experiment.

Introduction

The role and purpose of the science laboratory as a place to exposit abstract theories within a practical learning environment has drawn significant research attention (Boud et al., 1986; Hegarty-Hazel, 1990; Tobin, 1990). It can be a highly valued experience at school (Sneddon and Hill, 2011) and university (Deacon and Hajek, 2010) but, if constructed poorly or ill-placed in the curriculum, it can have a demotivating effect (Sheppard and Robbins, 2006) leading to a disconnect between its intentions and outcomes (Deters, 2005). Student perception of an experience can be a useful tool in ensuring alignment between intentions and outcomes (Biggs and Tang, 2007), and has been recommended as a key focus of future educational research attention in the laboratory (Hofstein and Lunetta, 1982). Student perceptions can be useful in development of psychometric instrumentation (Fraser et al., 1993) and to measure the impact of laboratory curricula innovations (Schroeder and Greenbowe, 2008; Abdullah et al., 2009).

This work represents a case study, in accordance with the definition published by Cohen, Manion et al. (2007), exploring how the timing of an experiment in the laboratory program affects the student perception of the experiment. The case study uses a variety of tools to explore student perception of a widely utilised experiment that typically forms part of an undergraduate organic (Mosbo et al., 1996) or mixed organic-inorganic (Wollins, 2002) synthesis laboratory program. Our analysis explores educational issues arising from this commonplace undergraduate student experiment within the context of the home institution implementation. Using the ACELL (Advancing Chemistry by Enhancing Learning in the Laboratory) approach, classical statistical techniques and some simple content analysis we explore why the student perception of this experience varies from marginally positive to dominantly negative across the course of 3 years in which its position in the program was varied. This exploration triangulates both quantitative and qualitative data from the workshop experience, and student feedback provided after its implementation at the home institution. From this exploration we present some suggestions that can be utilised to ensure that scientifically important, but often poorly perceived, laboratory experiences are of maximum educational benefit to the student.

The Experiment

The discovery (Kealy and Pauson, 1951; Miller et al., 1952) and structural elucidation (Wilkinson et al., 1952) of ferrocene was the genesis of organometallic chemistry and was very rapidly recognised as an important experiment in a students' exploration of this then new field (Rausch et al., 1957). As an extension to this experiment, the aromatic nature of ferrocene was soon after communicated (Woodward et al., 1952; Graham et al., 1957) and used in undergraduate laboratories to illustrate Friedel-Craft acylation (Bozak, 1966; Hartley and Temple-Nidd, 1975; Mayo et al., 2000). As the reaction does not go to completion, separation of the product from the starting material is required and has been illustrated by utilising separation techniques, such as thin-layer (Herz, 1966), column (Wade, 1978), and high-performance liquid chromatography (Haworth and Liu, 1976; Newirth and Srouji, 1995).

Context

This work describes the student perception of the 'Acylation of Ferrocene' experiment, a Friedel-Crafts acylation of ferrocene with acetic anhydride, using phosphoric acid as the catalyst, to form acetylferrocene. At this institution the experiment aims to develop underlying technical skills and provides a means of introducing the chemistry of electrophilic aromatic substitution and the metallocenes that are presented in the associated second year lecture course.

This experiment illustrates theoretical concepts in electrophilic aromatic substitution and that aromaticity is retained in the organometallic complex and can be exploited in much the same way as in benzene, in this case by Friedel-Craft acylation. This experiment also aims to develop competency in separation and purification by requiring students to develop a technique to separate the desired product from the reaction mixture. Ideally, students should also have an understanding of chromatography and separation of compounds. However, this is not essential, as students will learn these skills as part of the experiment. If they have not had much exposure to the principles of chromatography this may mean that they will require more demonstrator assistance in developing their method for purifying acetylferrocene. This experiment illustrates that techniques, such as column chromatography, can be applied to organometallic compounds, further reinforcing the overlap between organic and inorganic chemistry.

The students undertaking this experiment have studied aromatic chemistry at first year, as well as aromatic chemistry and spectroscopy in the previous semester at the second year level. The series of lectures concurrent with this experiment included theory of electrophilic aromatic substitution with examples of mono-substituted aromatics and metallocenes. This experiment was studied over three academic years, where changes in the experiment and its timing were made. In Year 1, the experiment was offered towards the middle of the laboratory program. For reasons beyond the control of this work, it was moved to be the first experiment of the semester in Year 2. Partly on the basis of this work, it was shifted back to the middle of the program in Year 3.

Methodology

The educational analysis of this experiment was undertaken using the ACELL approach. In this approach an experiment must undergo three phases of review; testing at a workshop, surveying in the institution and finally peer review. ACELL provides a suite of instrumentation that are used to gauge the students' perceptions of the laboratory experience (Buntine et al., 2007; Jamie et al., 2007; Yeung et al., 2011).

Participants at the ACELL workshop

This experiment was presented at an ACELL workshop at the University of Sydney prior to examination in the context of the Australian tertiary institution from which it originated. During this workshop 26 academics and 25 undergraduate students completed 33 experiments over a three day period. Six participants (a mix of academic staff and undergraduate students) completed this experiment, and they were asked to complete questionnaires immediately after the experiment and during the review of the education template later that day. These questionnaires cover both the implementation of the experiment away from the originating institution, the educational intent of the experiment and the individual experience of the experiment. The findings from the workshop questionnaires were then incorporated into the experiment and the analysis of the intentions of the experiment† before returning to the originating institution for further data collection. At this institution students were asked to complete an ACELL Student Laboratory Experience (ASLE) survey immediately after completion of this experiment during the three years of this study.

Instrumentation

ASLE asks students to respond to fourteen five-point Likert scale and five open-ended questions immediately after the laboratory experience. Items 1 to 12 are given a Likert scale from 'strongly agree' through 'neutral' to 'strongly disagree'. Item 13 asks about the time available for the experiment and is given a Likert scale from 'way too much' through 'about right' to 'nowhere near enough'. Item 14 asks about the overall laboratory experience and is given a Likert scale from 'outstanding' or 'very valuable' to 'worthwhile', 'of little value' or 'worthless'.

For items 1 to 12 the Likert scale is coded a +2 ('strongly agree') to –2 ('strongly disagree'). For item 13 the scale is assigned to +2 ('way too much time') to –2 ('nowhere near enough time'). For item 14 a +2 ('outstanding') to −2 ('worthless') scale has been applied. The same parameterisation for all items is used, but it is noted that the different Likert scales for Items 1 to 12, Item 13, and Item 14 alters the respondent interpretation and leads to a different pattern of responses. Thus, Items 1 to 12 are presented separately from Items 13 and 14.

The qualitative statements ask students to comment on the following aspects of the experiment; whether they enjoyed it (15), what were the main lessons to be learnt (16), what aspects of the experiment are enjoyable (17), what aspects need improvement and suggested changes (18) and any additional comments (19).

Undergraduate students at this institution

The three years of surveying collected 82 responses, of which 70 had completed items 1 – 14 and are included in this analysis. As time available for the experiment was found to be a major theme to comments from the qualitative analysis, the responses to the other thirteen Likert scale items for all three years of surveying were divided based on response to Item 13, where those students who responded that time was ‘sufficient’ (‘way too much’, ‘too much’ or ‘about right’, N = 25) were separated from the students who responded that time was ‘insufficient’ (‘not enough’, ‘nowhere near enough’, N = 54). A Wilcoxon–Mann–Whitney two-sample rank-sum test, with unequal respondents, was performed where the null hypothesis is no difference (Wilcoxon, 1945; Mann and Whitney, 1947). To assess the significance of the observed fluctuation of student response over the three years of this study a Kruskal–Wallis one-way analysis of variance by ranks was performed (Kruskal and Wallis, 1952). Statistical significance for both tests was determined at $\alpha = .05$ for two tails.

The qualitative responses to items 15 – 19 were analysed using a modification to the method outlined in Buntine and Read (2007). The comments were classified according to identified broad themes and whether the intent of the comment was positive or negative in relation to its theme. The categories were subsequently verified by ensuring that any single comment did not fall simultaneously into multiple categories. Once this process was completed the underlying intention of each comment was reassessed and tabulated to determine whether there were any dominant trends differing between the years and cohorts in the nature of the comments.

Study Limitations

There are limitations with this study, most obviously the convenient sample at a single institution using a self-report instrument. This brings forth issues of equivalence as data from different samples are compared, combined and inferences drawn. A mixed methods approach to this case study, where qualitative and quantitative data are equally utilised to triangulate a collective student perception at each data collection, should ameliorate some of these concerns. The inferential statistics should be treated as exploratory, and not as conclusive, given the limited scope of this case study.

Results

Workshop

The results from the workshop (Figure 1) illustrate that participants expected that students would find the experiment interesting, that time should be sufficient, and that it was overall a worthwhile experience. The limited number of respondents does not provide sufficient power to permit statistical inference. However, from the comments provided there were suggested improvements to assessment criteria identified. The qualitative statements reinforce the strengths, weaknesses and important lessons of this experiment.

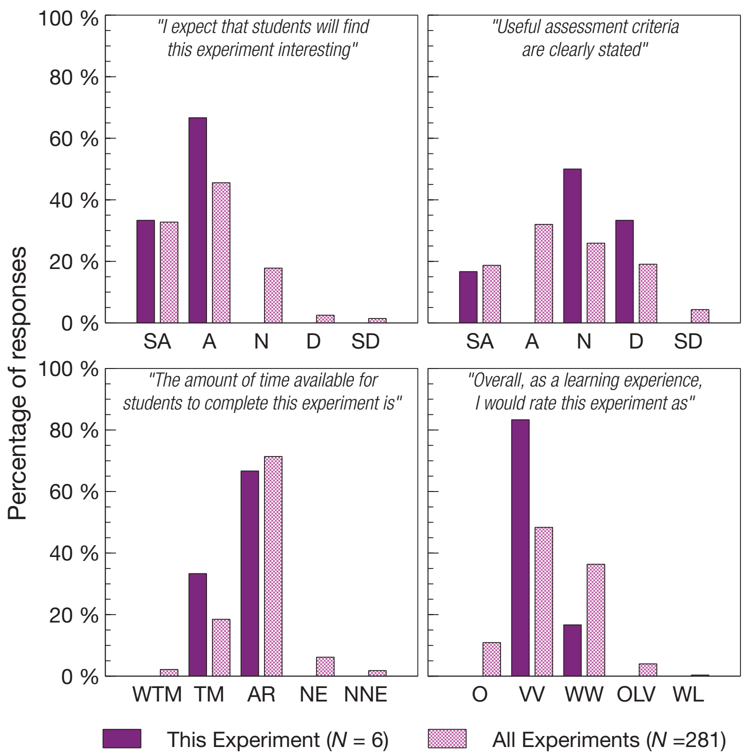

Fig. 1 Survey responses from the workshop survey for this experiment versus all tested experiments for four items.

> *"Experimental design - TLC analysis and subsequent column chromatography (which was not carried out during this workshop) seems like a good way to get students to*

think about the principles of chromatographic separation as it relates to the properties of the compounds in question, i.e. starting materials and product"

This comment strongly articulates the intended learning outcomes as outlined in the ACELL education analysis of this experiment.† Most importantly, while the reinforcement of theoretical knowledge from the lecture sequence is explicitly stated, for example:

"The experiment allows students to apply knowledge about electrophilic aromatic substitution to a case they may not have seen before".

This experiment is heavily dependent on demonstrator support in the laboratory:

"The ferrocene undergoes reactions during which it looks like it is wrong - Demonstrator input goes a long way to helping students in this prac"

This feedback from the workshop was incorporated into the educational analysis and changes were made to the experiment prior to implementation at the originating institution. The assessment criteria and mechanisms of assessment, once amended from the workshop feedback, were retained during data collection at the originating institution across the course of this study, and can be found in the supplementary information.†

Likert items at this institution

Figure 2 shows a summary of the Likert data collected from the three cohorts across the three years of surveying using ASLE at this institution. Some items are relatively consistent across the years; the assessment of the laboratory notes (Item 9), which did not change significantly, was statistically the same in each year. The responses to the "demonstrators" (Item 8) item is consistent and strong. "Relevance" (Item 10) is also perceived to be the same across the three years.

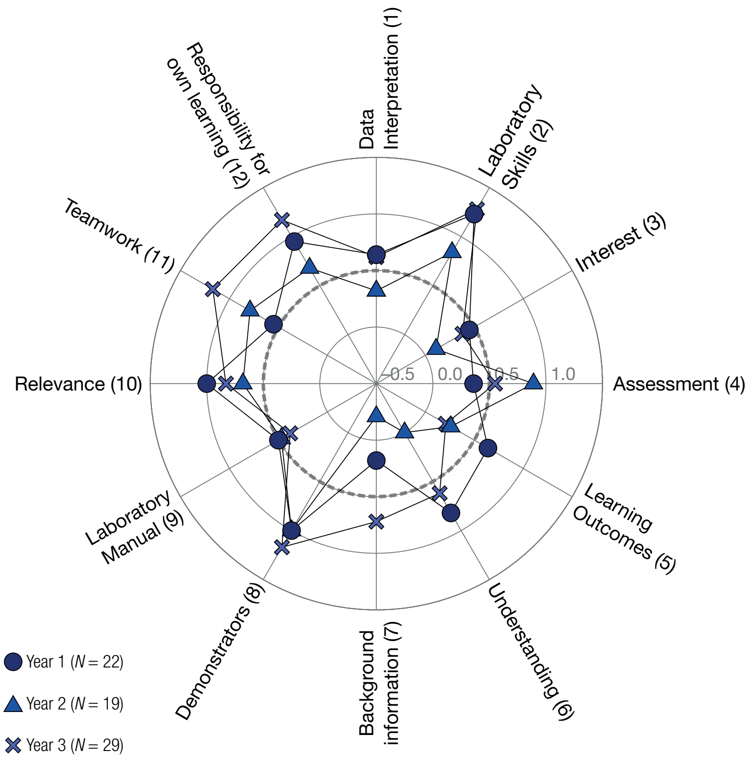

Fig. 2 A graphical representation of the parameterisation of students' responses to the quantitative statements on the ASLE instrument over the three years of surveying at the home institution illustrating the fluctuating perception of this experiment

Figure 1 also indicates that here are noticeable fluctuations in student perception for many items. In general, the responses to most items in Year 2 are not as strong as in Years 1 and 3. Two items, however, stand out. The responses to "Sufficient Background Information" (Item 7) and "Increased knowledge of Chemistry" (Item 3), are significantly lower in Year 2 than the other two years ($P < 0.05$, Kruskal-Wallis rank-sum test, see Table 1).

The final two Likert items on ASLE are measured on a separate scale to address two important influences on student perception, whether there is sufficient time to complete the experiment and whether the experiment itself was a worthwhile experience. The different scale and separation from Items 1 to 12 on the instrument typically require that the interpretation of these items is handled separately. In this case study, the dominating feature from these data was that students' felt there was insufficient time to complete this experiment (Item 13 mean: Year 1 = –1.05, Year 2 = –1.11, Year 3 = –0.76) regardless of where it was placed in the curriculum. There also appears to be a relationship between the student perception of adequacy of time available for the experiment, the year it was presented, and aspects of the overall learning experience. So the question arises, as to what aspects, in the context of this experience, influence the perception of time and place, and how might the teacher respond to ensure the objectives of the experiment are met?

Probing the perceptions of place

The place of this experiment in the sequence of experiments for the semester plays a significant role in its perception. The experiment was placed in the middle of the program during Years 1 and 3, but early in the semester in Year 2. Its placement at the beginning of the semester clearly impacted the student experience. However, despite placing such a technically demanding experiment early in the semester, the responses to the lab skills item (Item 2) are not statistically different between Year 2 and the other two years. The most significant differences between the years of surveying were observed (Table 1) for the items relating "understanding of chemistry" and "background information".

Table 1 A comparison of the mean parameterised responses for the fourteen Likert scale responses for all three years of surveying separated on the basis of response to item 13 and the Wilcoxon rank-sum parameters comparing these two groups

Item		**Insufficient (N = 47)**		**Sufficient (N = 23)**		**Wilcoxon**	
		Mean	**SD**	**Mean**	**SD**	**W(70)**	**p^a**
1	This experiment has helped me to develop my data interpretation skills	0.45	0.97	0.74	0.69	1584	.145
2	This experiment has helped me to develop my laboratory skills	1.15	0.72	1.13	0.87	1655	.435
3	I found this to be an interesting experiment	0.19	1.01	0.61	0.89	1550	.068
4	It was clear to me how this laboratory exercise would be assessed	0.53	1.04	0.70	0.93	1626	.300
5	It was clear to me what I was expected to learn from completing this experiment	0.45	1.12	0.17	1.23	737	.841
6	Completing this experiment has increased my understanding of chemistry	0.49	0.93	0.57	0.79	810	.532
7	Sufficient background information, of an appropriate standard, is provided in the intro	0.28	1.08	0.35	1.07	1651	.413
8	The demonstrators offered effective support and guidance	1.00	1.00	1.22	1.09	1586	.150
9	The experimental procedure was clearly explained in the lab manual or notes	0.28	0.97	0.78	1.09	1517	.029
10	I can see the relevance of this experiment to my chemistry studies	0.74	1.01	1.04	0.77	1586	.151
11	Working in a team to complete this experiment was beneficial	0.85	1.04	0.91	1.08	1650	.409
12	Experiment provided me with the opportunity to take responsibility for my own learning	0.85	0.81	1.22	0.67	1536	.048
13	I found that the time available to complete this experiment was	–1.43	0.50	0.04	0.21	*NA*	*NA*
14	Overall, as a learning experience, I would rate this experiment as	0.11	0.70	0.39	0.58	1571	.111

[a] *Highlighted items are significant at $p \leq .05$*

The responses to item 16, asking for identification of the important lessons in this experiment, are telling (Figure 3). In all years, students recognise technical skills as being an important lesson, which, indeed the experiment is designed to develop. However, almost 40% of students in Years 1 and 3 also recognised the importance of developing the concept of electrophilic aromatic substitution via the experiment. In Year 2 , however, no student commented on theoretical understanding as being important, whilst 75% commented on technical skills. As we discuss below, we attribute this to cognitive overload for the students in Year 2, who have not had the benefit of development of core skills in earlier experiments, nor introduced to the theory in lectures. As the development of concepts in organic chemistry, was one of the intended outcomes of this experiment, clearly the placement in the program needs to be considered carefully to achieve this intent.

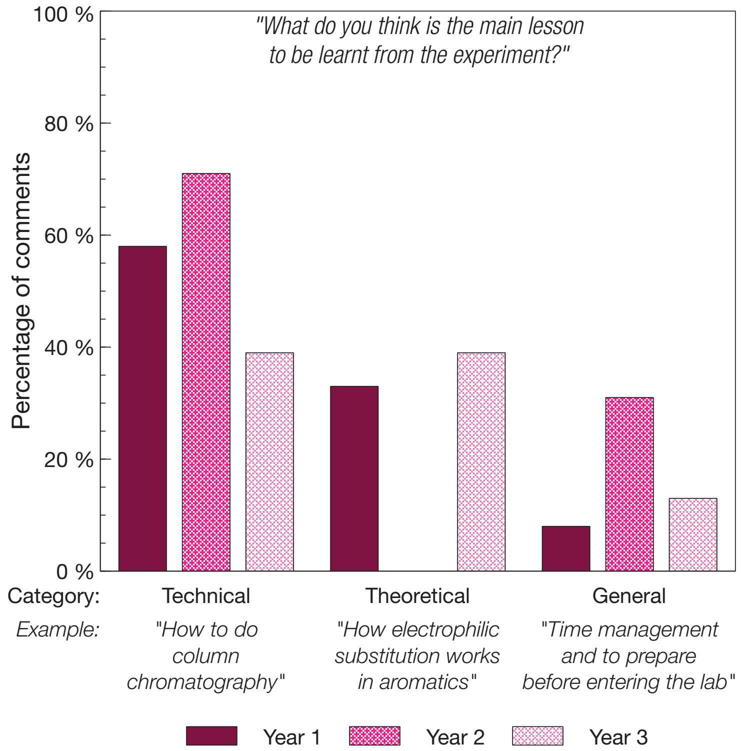

Fig. 3 Percentage of the number of qualitative responses to Item 16 from the ASLE surveying illustrating the pattern across three distinct themes identified across three years of surveying

Probing perception of time

The qualitative analysis identified seven categories, to which all comments could be aligned:

(1) Time: Adequacy of time within the lab session and or the quantity of work required to complete in the set time.

(2) Information: Quality and quantity of information in the introduction and/or laboratory notes.

(3) Resources & Demonstrators: Quality and accessibility of apparatus, chemicals, resources and the laboratory environment in general.

(4) General Skills: Skills that are not scientific in nature and/or related to generic graduate attributes.

(5) Technical Skills: Skills of scientific relevance, either practical or theoretical.

(6) General Interest: Interest in the experiment and/or theory related to the lecture course.

(7) Other: Comments that cannot be ascribed into any of the above categories.

The qualitative statements from students responding to items 15 – 19 indicate that the students found the experiment to be too long. Four time-related sub-categories of “time” were identified from the comments: tasks, resources, information or non-specific. The majority of the responses are of a technical or procedural nature and relate to the experimental procedure, as opposed to the conceptual capacity to successfully complete the experiment.

Examples of statements relating to time indicate the numbers of tasks the students were required to perform within the set time period. For example, when asked whether they enjoyed the experiment:

“No, too little time to do so many things”, (item 15, Year 2).

The next influence on time is the availability of resources. Several students commented on the fact that time was wasted while waiting for equipment to be available, for example when asked to comment on improvements to the experiment:

“Since time was lost waiting for equipment to become available equipment such as TLC jars should be made more available.” (item 19, Year 1)

While not a sentiment expressed by a significant number of students, it may relate to an underlying demotivating factor that could be easily rectified. In general, the students describe how multiple facets make up their demands on time and improvements to any of them may improve that perception. To achieve a meaningful comparison, the responses to Items 1–12 and 14 were categorised into two groups; students who responded that there was enough or too much time (N = 23) were separated from those who responded that there was not enough or nowhere near enough time (N = 47). A comparison of the distributions (Table 2) indicates that significant differences (P <

0.05) are observed about the perception of the quality of the laboratory notes (item 9) and taking responsibility for their own learning (item 12). This indicates that students who found there was sufficient time available for the experiment were more likely to perceive that the laboratory notes were clear and they felt they could operate as independent learners.

Table 2 A comparison of the mean parameterised responses for the fourteen Likert scale responses for all three years of surveying and the Kruskal-Wallis rank-sum parameters comparing these three groups

Item		**Year 1**		**Year 2**		**Year 3**		**Kruskal-Wallis[a]**	
		(N = 22)		**(N = 19)**		**(N = 29)**			
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	***H*(2)**	***p*[a]**
1	This experiment has helped me to develop my data interpretation skills	0.64	1.00	0.32	0.95	0.62	0.78	1.645	.439
2	This experiment has helped me to develop my laboratory skills	1.23	0.75	0.84	0.90	1.28	0.65	3.616	.164
3	I found this to be an interesting experiment	0.45	.91	0.11	0.94	0.38	1.08	1.099	.577
4	It was clear to me how this laboratory exercise would be assessed	0.36	1.09	0.89	0.88	0.55	0.99	3.144	.208
5	It was clear to me what I was expected to learn from completing this experiment	0.64	1.00	0.26	1.33	0.21	1.15	1.753	.416
6	Completing this experiment has increased my understanding of chemistry	0.82	0.85	0.00	0.94	0.62	0.73	8.615	.013
7	Sufficient background information, of an appropriate standard, is provided in the introduction	0.18	1.01	–0.21	1.03	0.72	1.00	9.625	.008
8	The demonstrators offered effective support and guidance	1.00	0.93	1.00	1.25	1.17	0.97	0.639	.727
9	The experimental procedure was clearly explained in the lab manual or notes	0.50	0.91	0.47	1.17	0.38	1.05	0.166	.920
10	I can see the relevance of this experiment to my chemistry studies	1.00	0.93	0.68	1.20	0.83	0.76	0.789	.674
11	Working in a team to complete this experiment was beneficial	0.55	1.06	0.79	1.03	1.17	1.00	5.552	.062
12	The experiment provided me with the opportunity to take responsibility for my own learning	0.95	0.84	0.68	0.75	1.17	0.71	5.394	.067
13	I found that the time available to complete this experiment was	–1.05	0.79	–1.11	0.88	–0.76	0.79	2.888	.236
14	Overall, as a learning experience, I would rate this experiment as	0.18	0.59	0.00	0.88	0.34	0.55	3.066	.216

[a] *Highlighted items are significant at $p \leq .05$*

One major outcome of the workshop review was an improvement to the laboratory notes to ensure that the theory of the experimental procedure was explicitly outlined. Regardless, there was a dominant sentiment in qualitative statements relating to the quality of information and description of techniques in the laboratory notes and pre-laboratory introduction by demonstrators, with a large number of students expressing comments such as:

> *"Better/Clearer instruction to make the whole experiment more achievable" (item 18, Year 3).*

It is interesting to note that the student perception of the amount of time coincides with that of the quantity and quality of procedural information and whether students taking responsibility for the own learning. This indicates a relationship between these factors, most probably a frustration with the lack of information provided making them more dependent on demonstrators, a limited resource, and therefore less independent as learners in this environment. Students frequently intimate this relationship in their statements, for example:

> *"Make demonstrators present during the experiment, so students have chances to ask questions" (item 18, Year 1)*

> *"Sometimes it is hard to find the demonstrator" (item 15, Year 1)*

The triangulation of data indicates that the laboratory notes play an important role in the perception of time available for this experiment, which in turn may impact on general utility in the laboratory learning environment. This coincides with the identification of primarily technical learning outcomes as a main outcome of this experiment, which must largely be communicated by the laboratory notes or the demonstrators who supervise this experience. It was found from the comments that students did not express a dissatisfaction with the experiment itself, but rather with the lack of resources available to complete it within the time allocated.

Discussion

The student perception, from this case study, of the educational benefit of the acylation of ferrocene experiment is largely within two realms, technical skills development and an illustration of relevant theory. These outcomes relate strongly to the educational intent of the experiment as outlined by the detailed ACELL educational analysis, which states that the main objectives are the application of the Friedel-Craft acetylation of an organometallic compound and utilising chromatography to achieve separation of the desired product from the reaction mixture.† However, an analysis of student responses to surveys at the home institution shows a highly varied perception of this experiment, largely dependent on the amount of time required to successfully complete it.

The fluctuating student perception of the acetylation of ferrocene experiment provides some interesting insights into what drives student perception of a synthesis experiment, especially in time-poor scenarios. There are two aspects to this analysis – the placement of the experiment in the program and the perception of amount of time. Although linked, analysis of these issues provides a complementary view of the experience.

The main impact of moving the experiment to the first week of the program is that the students' perception of the learning objectives shifted from split between technical and theoretical to 100% technical. There is nothing fundamentally wrong with a skills-based experiment that is pitched at the confirmatory end of the inquiry spectrum (Buck et al., 2008) if the learning outcomes are purely skill-focused. However, the intended learning outcomes of this experiment included conceptual knowledge and so, for the experiment in Week 1, this objective is not met.

There are two considerations to the failure to meet the theoretical objectives: Firstly, in Week 1, the students have not yet met the concepts in lectures. Clearly, the background information in the laboratory notes is insufficient to support this learning in the laboratory (Items 6 and 7 in Table 1). In mid-term, after introduction in lectures, the background information becomes sufficient and the students perceive the theoretical objectives. Secondly, the experiment could have been given a more inquiry focus, requiring the students to learn the theory independently. However, there is insufficient time in the experiment in its current guise for this to happen in Week 1 where there are so many new skills to learn.

The second aspect to this analysis concerns the students' perception of the time allotted to complete the experiment. Interestingly, there is no statistically significant difference in this perception between Year 2 and Years 1 and 3. As discussed above, the students simply lost the perception that they were supposed to be learning organic chemistry concepts in Year 2, and only considered technical aspects of their learning.

In the analysis where responses are separated by perception of time, a different story emerges. Where time is precious, the student perception of the laboratory notes, and their responsibility for their own learning have the greatest impact (Table 2). It is interesting that these are different items to the ones that are change when the experiment placement is changed, which points to a different origin. Whether these themes are causal or symptomatic of the fluctuating perception is not immediately clear. For example, do students who understand the notes have more time, or does a feeling of insufficient time cause an over-reliance on the notes? We do not collect data on student demographics, such as not being native English speakers, so this remains an open question.

The connection between having sufficient time and the students' responsibility for own learning is clearer. Responsibility for own learning is a catchall item in ASLE to probe the level of independent learning, or level of inquiry. It is well-recognised that experiments that aim at authentic inquiry (Buck et al., 2008) have time as a mediating influence on the student perception (Baseya and Francis, 2011). Indeed, it is a frequently heard complaint by school and college teachers that there is simply not enough time to do inquiry (Brown et al., 2006). This experiment was never intended to be anything but confirmatory as far as technical skills are concerned and structured inquiry for conceptual knowledge. Even within the same cohort, and independent of the place in the laboratory program, students who, for whatever reason, understood the notes and believed they had enough time, had a much more positive response to taking "responsibility for their own learning".

Student laboratory activities are traditionally very explicit in the details necessary for completion of all aspects of the experiment (Fisher et al., 1998; Hofstein and Lunetta, 2004), often to the detriment of the intended outcome (Johnstone and Wham, 1982). In this case study, the lack of responsibility for own learning may well be caused by the student perception of the inadequate time, which may arise from perceived inadequacy of the procedural notes (Jordan et al., 2011). These implications and the underlying observations from this case study are entirely congruent with Cognitive Load Theory (Paas and Merriënboer, 1994), where a lack of experience with experimental techniques leads the novice to focus entirely on the skills necessary to complete the tasks (Anderson, 1987) and to turn away from independent learning.

Implications for practice

There were two contributing factors to the fluctuating perception of this experiment. Firstly, that the placement of this experiment in the laboratory program, as it was designed, is crucial to ensure it is undertaken after completion of the necessary theory in the accompanying lecture sequence. A key aspect of the student perception in Year 2, where the experiment was before much of the lecture content, was a focus entirely on technical aspects of the experiment, perhaps through a lack of comprehension of the underlying theory of the reaction and its importance to the discipline. The alignment of the conceptual and theoretical intentions of the experiment with an understanding of the students' background ensures maximization of expectations of and attitudes toward the outcome (Baseya and Francis, 2011). Secondly, the focus on technical aspects in the absence of a theoretical basis leans heavily on the resources, information and staff in this case.

In an environment where the instructor has the opportunity to make significant changes to the experiment, or even change the pedagogy of the laboratory program, then there are alternate pedagogical approaches that can be considered that lessen the need to have closely integrated or sequenced learning experiences.. Inquiry-oriented strategies apply a hierarchy of levels to practical tasks (Hegarty, 1978), from structured and guided inquiry (Lamba and Creegan, 2008; Schroeder and Greenbowe, 2008) to fully open-ended tasks (Roth, 1994) that can provide opportunities for students to gain higher-order process skills (Roth and Roychoudhury, 1993) and a greater ability to adopt scientific ways of doing (Spronken-Smith and Walker, 2010). These strategies present mechanisms for the empowered instructor to create a self-contained laboratory learning experience that garners the desired student learning outcomes and a positive perception, as well as more elusive higher order skills, such as self-regulation in the laboratory learning environment.

In situations where the instructor is more constrained in the ability to make significant change, an analysis such as presented in this case study can still be used to optimise the student experience. Obviously, choosing the correct sequencing of the experiments should be done. By considering the requisite skills, ensuring that the students have had an opportunity to develop these skills, and sequencing this experiment appropriately, the instructor can then afford the students the opportunity to explore the intended outcomes relating to the mechanism of addition to this organometallic complex without wholesale changes to the pedagogical approach. Even if the experiment was constrained to Week 1, then we would suggest that aligning the assessment with achievable learning objectives (in this case technical), and using only formative assessment for the theory would improve the student experience.

Conclusions

In this case study we present evidence that the overall placement of an experiment in the laboratory program, and the individual students perception of the adequacy of the allotted time can significantly change the student experience. The positioning of the experiment early in the semester, without lecture scaffolding of the theoretical concepts leads to the student perception that the intent of the experiment is purely skills-focussed. When performed after concepts are introduced in lectures the students recognise that the experiment also has intended theoretical learning outcomes. Irrespective of the placement in the program, students who have enough time for the technical process are able to establish some measure of responsibility for their own learning. We also present some implications for the instructor in situations where they either have control over the laboratory syllabus, and where they can exert limited influence.

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Notes

† Electronic Supplementary Information (ESI) available: assessment criteria and ACELL educational analysis are available. See DOI: 10.1039/c3rp00011g/

‡ Likert response text for Items 1–12: SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree; Item 13: WTM = Way Too Much, TM = Too Much, AR = About Right, NE = Not Enough, NNE = Nowhere Near Enough; Item 14: O = Outstanding, VV = Very Valuable, WW = Worthwhile, OLV = Of Little Value, WL = Worthless

§ For items 1 to 12 the Likert scale has been assigned a +2 (strongly agree) to –2 (strongly disagree). For item 13 the scale has been assigned to +2 (way too much time) to –2 (nowhere near enough time). For item 14 a +2 (outstanding) to –2 (worthless) scale has been applied.

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