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A Cross-Institutional Perspective of Pre-Laboratory Activities in Undergraduate Chemistry

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Abstract

Pre-laboratory exercises may help reduce cognitive load in the laboratory, boost confidence, develop theoretical understanding and skills, and improve grades on assessment tasks. This study compared pre-laboratory activities at two institutions, Go8-1 and Go8-2, to evaluate which attributes of pre-laboratory activities were perceived by students to best prepare them for laboratory classes. Students were surveyed towards the end of their laboratory course, and were asked a series of Likert-style and open response questions. Factor analysis was used to construct three scales, incorporating items relating to performance and understanding, items relating to affective and personal laboratory experience, and items relating to requiring support with laboratory equipment. No difference between cohorts was observed between the two institutions regarding requiring support with equipment. While Go8-1 students rated performance and understanding more highly than Go8-2 students, the opposite result was observed for affective and personal factors. The factor analysis results and responses to the open response questions indicated that students felt most prepared for laboratory exercises when the pre-class activities touched upon all aspects of the laboratory class. It is recommended that quizzes and video be used in pre-laboratory activities, with these resources covering theory, aims, methods, calculations and data analysis.

Introduction

Laboratory classes form an important component of the general chemistry curriculum, and are where first-year students often spend up to half their class time at the institutions in this study. These institutions, Go8-1 and Go8-2, are both members of the Group of Eight (the eight highest-ranking research and teaching institutions in Australia). Laboratory classes are often designed to help students understand and apply theory, develop practical and critical thinking abilities, and practice transferable skills such as teamwork and communication (George-Williams et al., 2018; Reid & Shah, 2007). Johnstone (2006) and Agustian and Seery (2017) explain that the development of these multiple learning objectives by students requires them to focus on many tasks in a short period of time, which leaves very little cognitive load available for optimal learning. For example, in one experimental class a student may need to:

1) process verbal and written instructions,
2) make and note observations,
3) record and analyse data,
4) draw links between theory and experiment,
5) recall practical skills from previous classes, and
6) communicate effectively with staff and other students.

This can often lead to blind ‘recipe-following’ that results in a poor understanding of why steps undertaken are necessary, and can lead to future experimental mistakes (Hunter, Wardell, &

Wilkins, 2000). One means to combat this is the introduction of pre-laboratory exercises, which can help relieve cognitive load, assist the formation of links between theory and experiment, and lead to more reflective and analytical behaviour in the laboratory (Johnstone, 1997; Winberg & Berg, 2007).

Pre-laboratory exercises can assist students who may find interpretation of laboratory instructions and observations difficult, as well as those who are new to studying chemistry (Chittleborough & Treagust, 2008). The notion that students unfamiliar with chemistry may require more pre-class preparation is supported by a study investigating the use of simulation as a pre-laboratory exercise (Schmid & Yeung, 2005). For students who had studied chemistry before, there was no significant increase in laboratory marks after completing a pre-laboratory exercise, however a statistically significant increase for students who had not studied chemistry in upper secondary school was observed.

While the use of pre-laboratory tasks is recommended, the exact composition of these tasks is important to consider. Simulations and virtual laboratories used in pre-laboratory activities can provide students with insights into the laboratory exercise before attending class. Virtual laboratories have been used to help students learn laboratory layouts (Clemons, Fouché, Rummey, Lopez, & Spagnoli, 2019) and become familiar with equipment. Blackburn, Villa-Marcos, and Williams (2019) used simulations as pre-laboratory exercises where students could practice taking measurements and setting up apparatuses before performing similar work in the laboratory. Student production of synopses and flowcharts before the laboratory can also help improve performance as these artefacts help students to develop a better understanding of the experiment, help connect theory and practice, and reduce the amount of class time students spend reading instructions (Davidowitz & Rollnick, 2001; Rollnick, Zwane, Staskun, Lotz, & Green, 2001). Even though students respond positively to simulations, synopses and flowcharts, other preparation activities such as readings and quizzes are common in the literature, and are at times a preferred preparatory tool (Agustian & Seery, 2017; Dalgarno, Bishop, Adlong, & Bedgood Jr., 2009).

A quiz-based pre-laboratory activity can be designed to give students feedback such that their theoretical and experimental ability is developed before attending laboratory classes (Chittleborough, Mocerino, & Treagust, 2007). Students reported via an online questionnaire that this style of quiz helped them learn from their mistakes, and that the quizzes helped boost understanding and confidence. Similarly, in a questionnaire-based study by Whittle and Bickerdike (2015), 85% of students reported increased confidence, and 90% of students thought they better understood the theory after completing a preparatory quiz. Interviews with students following the introduction of a quiz-based pre-laboratory task focusing on background and contextual information indicated that quizzes lead to students feeling better prepared and engaged (Mercer-Chalmers, Goodfellow, & Price, 2004).

Similar findings regarding the benefits of quizzes have also been observed with the use of video in pre-laboratory tasks (e.g. Stieff, Werner, Fink, & Meador, 2018). In one study, students who watched preparatory videos scored their preparedness for the laboratory class 0.77 out of 5 higher, on average, than those who didn't watch the videos (Rodgers et al., 2020). Videos that provided insight into the experiment by showing equipment assembly, and summarising expected observations and results led to an average improvement in a post-laboratory test of 10% relative to a pre-test. Students who did not watch the video only had an average improvement of 4% (Nadelson, Scaggs, Sheffield, & McDougal, 2015). An added benefit of video is that it allows students to pick up on visual details that may not be outlined in writing (Teo, Tan, Yan, Teo, & Yeo, 2014).

A mix of videos and quizzes as preparation tools resulted in 70.3% of students commenting that they found the videos useful, and 77% reporting that the pre-laboratory material helped improve understanding (Spagnoli, Wong, Maisey, & Clemons, 2017). Chaytor, Mughalaq, and Butler (2017) used videos that outlined experimental technique and quiz questions that aimed to facilitate linking between observations and theory to prepare their students. Student feedback indicated that the pre-laboratory exercise led to increased feelings of preparedness and confidence, and a better understanding of equipment setup (Chaytor et al., 2017). Students also took less time to complete the experiment and asked fewer methodological questions. Similar results have been observed elsewhere for comparable pre-laboratory activities (Moozeh, Farmer, Tihanyi, Nadar, & Evans, 2019; Veiga, Luzardo, Irving, Rodríguez-Ayán, & Torres, 2019), and also with extended quizzes to incorporate safety aspects and/or calculations (Altowaiji et al., 2021; Jolley, Wilson, Kelso, O'Brien, & Mason, 2016; Sarmouk et al., 2020). However, it was noted by Altowaiji et al. (2021) that the inclusion of calculations in the pre-laboratory quiz did not necessarily lead to better analysis and result interpretation in the laboratory class.

Pre-laboratory quizzes are one of the most common laboratory preparation techniques, and are also employed by Go8-1 and Go8-2, with Go8-1 also providing students with a video for most experiments. Prior questionnaires of student perceptions of preparatory activities typically involved only one institution and style of quiz activity, therefore this study compares student responses across the aforementioned universities to compare perceptions between institutions that have differing laboratory learning intentions, pre-laboratory design and implementation. The focus of this study is on the following two questions:

- Which aspects of existing pre-laboratory quizzes do students most value and why?
- What are the characteristics of a pre-laboratory activity that students think would best prepare them for laboratory classes?

This study focuses only on student perceptions and does not include teacher assessments of preparedness.

Methods

Description of the pre-laboratory exercises

The laboratory course at Go8-1 comprised four one-week expository experiments and two two-week guided inquiry experiments. Each student completed every experiment. This contrasts with Go8-2, where students were assigned to complete 9 out of 10 expository experiments. For their post-laboratory assessment, students at Go8-1 were required to complete a practical report including aim, methods, results, discussion and conclusion sections, whilst Go8-2 students were graded in class. Laboratory classes were held on campus, with one teaching associate responsible for approximately 16 students at each institution. At both institutions, the laboratory course formed a small part of a student's final subject grade. See Table 1 for more information regarding assessment, cohort and subject characteristics of both institutions.

Table 1: Characteristics of the laboratory and lecture course at Go8-1 and Go8-2.

Characteristic	Go8-1	Go8-2
Number of expository experiments	4	9
Number of guided inquiry experiments	2	0
Laboratory course duration	8 Weeks	9 Weeks
Laboratory assessment	Online laboratory report	In-class assessment
Weight of laboratory assessment towards the final subject grade	30%	15%
Lecture course content	Introductory organic, inorganic, biochemistry and electrochemistry	Introductory organic, inorganic, electrochemistry and kinetics
Lecture course duration	12 Weeks	13 Weeks
Prerequisites	None	Year 12 chemistry (or equivalent) or none depending on enrolment
Secondary school achievement level	High	High
Student composition	Domestic and international	Domestic and international

Both universities required students to complete a graded pre-laboratory activity before attending classes, including a quiz presented on their respective learning management systems for each experiment (*Moodle* for Go8-1 and *Canvas* for Go8-2). The Go8-1 quizzes included three to 11 questions, while most quizzes at Go8-2 had five. Questions at Go8-1 asked students about theory, the aims of the experiment, methods, experimental techniques, calculations, data analysis and safety procedures, with the types of questions asked varying quiz-to-quiz. The quizzes at Go8-2 took a more formulaic approach, with at least one question covering some theory, aims, methods, experimental technique and/or safety procedures per quiz. Only one question at Go8-2, across all quizzes, asked students to complete a practice calculation. The Go8-1 pre-laboratory activity also, generally, included a video. Most videos provided a short theory or background section, an overview of the experiment, demonstrations of new equipment (if any) and example calculations or analyses (Refer to Tables 1 and 2 of the Supplementary Material for more detail). The quizzes were due 30 minutes before the start of class at Go8-1, and students were not allowed to enter the laboratory if a pass mark on the quiz had not been obtained. The quizzes at Go8-2 were nominally due at the start of class, however this was not checked or policed, resulting in varied student engagement with the quizzes before the start of class.

Questionnaire

Students studying first-year, general chemistry at Go8-1 and Go8-2 were invited to complete a paper-based questionnaire in the final week of semester or the penultimate week of laboratory class, respectively, in Semester 2, 2018. Consent was implied if students returned their survey form. The survey comprised questions about demographic details, open response questions about pre-laboratory resources and preferences, and a series of 29 Likert questions. A five-option Likert scale was used: strongly disagree, disagree, neutral, agree and strongly agree. The Likert and open response questions were adapted from, or inspired by, those in previous studies (Chittleborough et al., 2007; Dalgarno et al., 2009; Gregory & Di Trapani, 2012; Szteinberg & Weaver, 2013; Whittle & Bickerdike, 2015).

Data analysis

To minimise Type I errors introduced due to undertaking many comparative tests, such as t-tests, factor analysis was used to sort the Likert responses into factors. Likert questions were sorted into a factor if the loading was greater than 0.3. Scores for each factor were generated by assigning values to the Likert options and summing student responses (Boone Jr & Boone, 2012). Values assigned were 1 for strongly disagree, 2 disagree, 3 neutral, 4 agree and 5 strongly agree. For example, the Equipment Support factor combines Likert items 2, 3, 4 and 20. A participant who responded strongly disagree, neutral, agree and agree to those items, respectively, would have an Equipment Support score of 12 (1 + 3 + 4 + 4). More detail regarding the factor analysis results is presented in the results section and in the Supplementary Material.

Normality was tested via visual inspection of the factor score histograms. All plots were normally distributed, with a few outliers. As normality was confirmed, an independent samples t-test was undertaken to determine the difference in student responses of the two university cohorts (Tabachnick & Fidell, 2013). All quantitative analysis was undertaken using SPSS version 25 or 26.

The open response questions were analysed by thematic analysis. To ensure inter-rater reliability, all authors themed 10% of the Go8-2 responses and approximately 33% of Go8-1 responses to ensure an equal number of responses (N = 46) were themed from each university. Following this, the authors used a consensus approach to determine the themes for all responses previously coded. Once the theme set was determined, all authors themed a new batch of open response questions, again 10% of Go8-2 and an equal number of Go8-1 responses. Inter-rater reliability was determined using Krippendorf Alpha (Hayes & Krippendorff, 2007; Krippendorff, 2004). K-alpha values of 0.93, 0.84, 0.94 and 0.88 were obtained for open response questions 1, 2, 3 and 4, respectively. Since high reliability was obtained, a single author themed all responses based on the author team's previous discussions. Themes were considered for analysis if 10% or more responses were coded that theme for either the Go8-1 or Go8-2 cohort (George-Williams et al., 2018).

Results and discussion

Demographics

A greater proportion of Go8-2 students submitted surveys, compared to those studying at Go8-1, with response rates of 59.9 and 15.2%, respectively (Table 2). It is likely that the low response rate at Go8-1 compared to Go8-2 was due to the survey being administered at Go8-1 during the final non-compulsory tutorial of the semester, while the Go8-2 survey was completed during compulsory laboratory sessions. At both institutions, more females than males returned surveys (Table 3). Very few Go8-1 students (10%) reported not completing Year 12 chemistry compared to 22% of Go8-2 students.

Table 2: The number of students who responded to the survey administered at Go8-1 and Go8-2.

University	Student responses	Number of students enrolled	% responded
Go8-1	141	930	15.2
Go8-2	461	770	59.9

Table 3: The number of student responses to each demographic question.

Characteristic	Response	Number of responses	
		Go8-1	Go8-2
Gender identified as	Male	61	158
	Female	76	299
	Other or rather not say	2	2
Level of secondary school chemistry studied	Did not complete high school chemistry	7	22
	Year 7-10	4	42
	Year 11	3	27
	Year 12	125	361

Factor analysis

Factor analysis sorted the Likert responses into three factors:

- Performance/Understanding: items related to pre-laboratory exercises improving performance and understanding in the laboratory class (16 items).
- Personal/Affective: items related to personal laboratory experience and affective factors in the laboratory class (8 items).
- Equipment Support: items related to requiring more support with equipment (4 items).

Likert item 10 had a loading greater than 0.3 for two factors, however was only sorted into the factor with the higher loading, Personal/Affective. Likert item 29 was not sorted into any factor as all loadings were less than 0.3. The loadings for the Personal/Affective factor were both positive and negative, therefore for Likert items 8, 9 and 10, the response options were reversed before a factor score was calculated to ensure directional effects were maintained (i.e. strongly agree became 1, strongly disagree became 5). To reduce the impact of Type I errors, a Bonferroni correction was applied such that $p \leq 0.017$ was required to consider the results statistically significant, rather than $p \leq 0.05$ (Tabachnick & Fidell, 2013).

Performance/understanding

The average Performance/Understanding score for Go8-1 students was higher than that of Go8-2 students, at 57 and 51, respectively, out of a maximum possible score of 80 ($p < 0.001$, Table 4). This result indicates that more Go8-1 students believed that the pre-laboratory exercises aided their performance and understanding in the laboratory compared to Go8-2 students. This is particularly evident in Likert items 27 and 28, where a greater proportion of Go8-1 than Go8-2 students agreed or strongly agreed that the pre-laboratory exercises helped them to analyse data and perform calculations (see Figure 1, below, and Table 3 of the Supplementary Material). Other Likert items with large differences between cohorts, were items 12 (I have to read the laboratory instructions before completing the pre-laboratory exercises) and 14 (The pre-laboratory exercises boost my confidence about the laboratory class). Also of interest were Likert questions 18 and 19, where a greater proportion of Go8-2 students strongly disagreed or disagreed that the pre-laboratory exercises helped them to operate or assemble equipment. Apart from these items, the responses were similar across the two institutions.

Table 4: Average factor scores for Go8-1 and Go8-2 students.

Factor	University	Number of students	Mean score	Standard deviation	Maximum possible score	t-test significance (2-tailed)
Performance/ Understanding	Go8-1	132	57	10	80	< 0.001
	Go8-2	418	51	13		
Personal/ Affective	Go8-1	133	26	5	40	< 0.001
	Go8-2	424	28	5		
Equipment Support	Go8-1	132	11	3	20	0.55
	Go8-2	422	11	3		

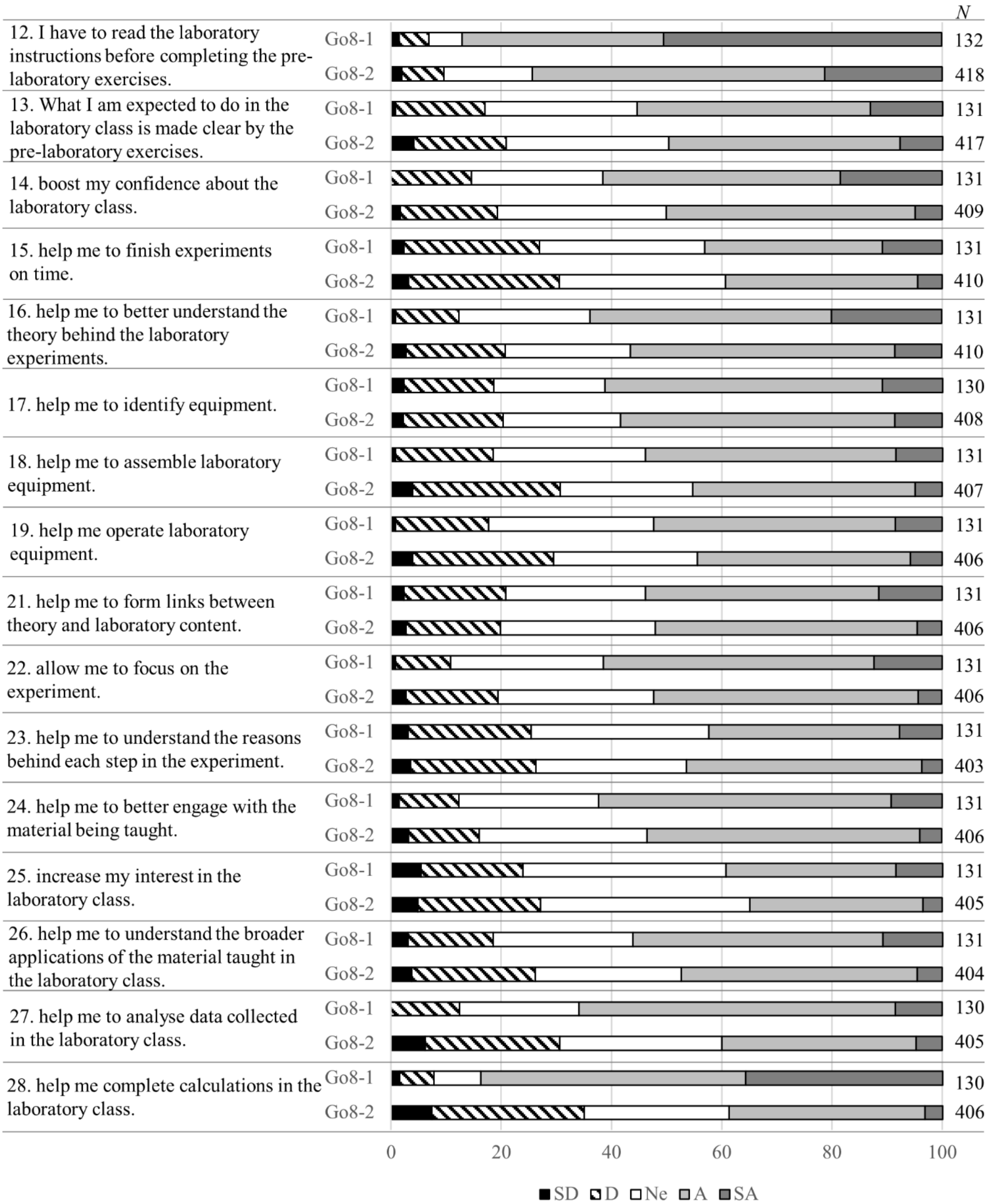

Figure 1: The percentage of student responses for each Likert option for questions that were classified into the Performance/Understanding factor. Items 14 to 28 started with the phrase "The pre-laboratory exercises…". Likert options were strongly disagree (SD), disagree (D), neutral (Ne), agree (A) and strongly agree (SA). ***N*** **number of students responded to each question.**

Comparing these results to the structure of the pre-laboratory activity, the Go8-1 activity used video to teach theory and experimental information, asked more theory questions, and incorporated practice calculations or analyses in most quizzes. Only one quiz at Go8-2 asked students about calculations or analyses. The findings suggest that the theory, calculations, and analysis questions may be important for improving student's perception of their performance and understanding in the laboratory. Though, pre-laboratory quizzes do not necessarily improve student grades (Kennephohl, 2001), there are many reports of pre-laboratory quizzes boosting student perception of improved performance and understanding (Gregory & Di Trapani, 2012; Mercer-Chalmers et al., 2004; Nicholls, 1999).

The notion that Go8-1 students believed that the pre-laboratory exercises aided their performance and understanding in laboratory classes was also supported by the open-response questions (Figure 2). The major themes identified in the Go8-1 cohort associated with which aspects of the pre-laboratory exercises were helpful in preparing them for laboratory classes were 'Calculations', 'Methods', 'Aims' and 'Video' (Table 5). A typical 'Calculations' related response is from Participant Go8-1-43 who said the pre-laboratory exercises "*Often required us to do calculations and answer questions which were similar to those in the lab and lab report, allowing us to be more prepared*.", suggesting that practicing the exact material presented in the laboratory class before-hand is beneficial to being able to complete calculations and analyses in class. This is supported by comments themed as 'Methods', 'Aims' and 'Video', as these typically expressed that quiz questions relating to methods and aims, and visual demonstrations helped students understand what to expect and how to complete the practical aspects. This sentiment was observed across both Go8-1 and Go8-2 cohorts, except for the 'Video' theme, which was only discussed by Go8-1 students as the Go8-2 pre-laboratory did not incorporate video. In addition, video can improve knowledge transfer and practical skill by providing students visual cues that may not be possible through text (Nadelson et al., 2015; Teo et al., 2014).

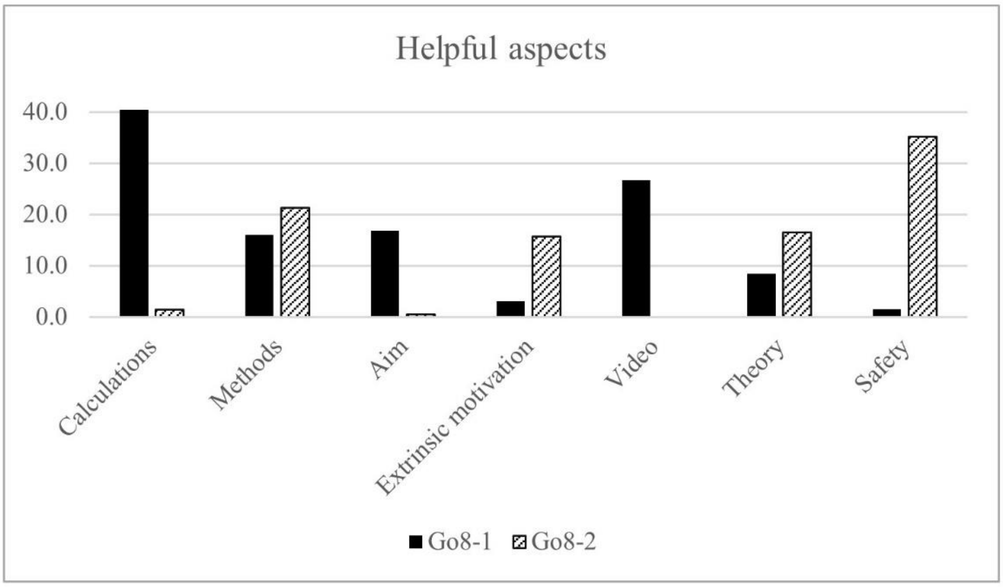

Figure 2: The percentage of students whose open response questions were themed into each category for Question 1: Which particular aspects of the pre-laboratory exercises were helpful in your preparation for laboratory classes? (Please explain why). Theme definitions are outlined in Table 5.

Table 5: The themes and their definitions, with examples, for the open response question "Which particular aspects of the pre-laboratory exercises were helpful in your preparation for the laboratory classes? (Please explain why)".

Theme	Definition	Example
Aim	Determining the aim before class.	"Coming up with the aim in the pre-lab was helpful because it forced me to read through the manual thoroughly and actually understand it before moving on." (Go8-1-2)
Calculations	To practice or gain awareness and understanding of calculations.	"Pre-lab exercises prepared us for the type of calculations we'd be doing." (Go8-1-1)
Extrinsic motivation	Being forced or encouraged to complete the pre-laboratory exercise.	"The questions 'forced' me to read the laboratory notes and have an adequate understanding at what I was going to be doing in the lab which was helpful." (Go8-2-388)
Methods	Which methods, skills and experimental techniques will be used. Being given an expectation of what will happen in class.	"They were very helpful to help me understand exactly what I was required to do." (Go8-1-25) "Reading the method & making links between different parts of the experimental design was helpful to me because then I could understand the significance behind each step. It also made me conduct the lab work more efficiently." (Go8-2-409)
Safety	Risk assessment, safety protocols, or waste disposal and management.	"Risk and hazard analysis. Because it can make student avoid [accident] and it really help to make myself more careful when I used chemicals." (Go8-2-90)
Video	Reference to videos or being shown aspects of the theory, experiment or analysis in video format.	"Some had videos demonstrating what we would be doing in the lab that showed us what we would be doing. They helped us understand and know the aim of the experiment." (Go8-1-8)
Theory	Understanding theory, concepts or topics.	"Understanding because information is important." (Go8-1-27) "The quizzes because they made me read the prac and learn the theory behind it." (Go8-1-95)

Table 6: The themes and their definitions, with examples, for the open response question "How could the pre-laboratory exercises be changed to improve your preparation for laboratory classes? (Please explain why)".

Theme	Definition	Example
Method	Which methods, skills and experimental techniques will be used. Being given an expectation of what will happen in class.	"Use more examples of what we are actually doing in the lab." (Go8-1-54) "Go over techniques that will be used in lab such as how to use equipment." (Go8-1-81)
None	No improvements.	"I don't think any changes are needed." (Go8-2-342)
Relevance	Explain the context, background, purpose and/or relevance to lectures. Better scaffolding between the pre-laboratory exercise and the laboratory class.	"If the content was directly linked to the labs and gave us an opportunity to learn and understand what we were doing in the lab rather than giving a vague idea." (Go8-1-134)
Theory	Understanding theory, concepts or topics.	"Ask more specific questions about the theory behind the practical chemistry" (Go8-2-193)
Video	Reference to videos or being shown aspects of the theory, experiment or analysis in video format.	"Maybe add some video about the lab. When the first time come in lab, it is hard to try to do all thing by myself and it takes really long time for me to be familiar with the lab." (Go8-2-90)

Personal/Affective factors

Even though Go8-1 students believed that the pre-laboratory exercises improved their performance and understanding in laboratory classes to a greater extent compared to Go8-2 students, Go8-2 students responded more positively than Go8-1 students on the Personal/Affective factor (an average of 28 compared to 26, $p < 0.001$, Table 4). This factor grouped Likert responses relating to feelings of confidence and preparedness; being able to work at your own pace; anxiety; not having too much to learn; not relying on others during class; and understanding the reasons behind each step of the experiment (Figure 3). This seemingly incongruous result between Performance/Understanding and Personal/Affective could be a result of how the laboratory classes are assessed, as well as the perceived difficulty of the laboratory experiments at both institutions.

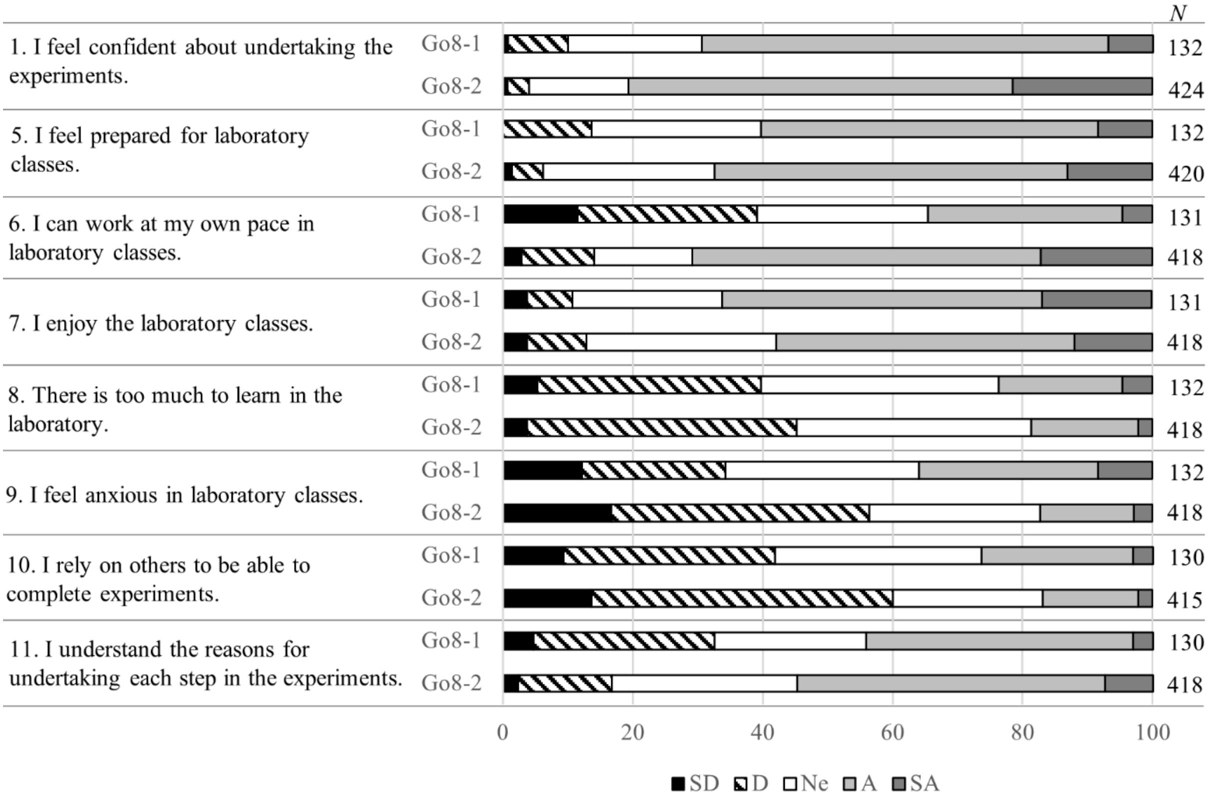

Figure 3: The percentage of student responses for each Likert option for questions that were classified into the Personal/Affective factor. Likert options were strongly disagree (SD), disagree (D), neutral (Ne), agree (A) and strongly agree (SA). ***N*** **number of students responded to each question.**

Go8-1 students were required to complete an online laboratory report after their class, typically requiring students to write an aim, summarise the methods, present and analyse results, and write a discussion and conclusion. On the other hand, Go8-2 students did not complete a laboratory report and instead were graded on laboratory skills, and in-class performance. This difference likely meant that Go8-1 students were under more stress to understand both the theoretical and practical components of each experiment, whilst Go8-2 students could focus on the practical tasks only. This conclusion is supported in the open response questions, where more Go8-1 students stated that the pre-laboratory exercises needed more theory coverage, better scaffolding between theory and experiment (the ‘Relevance’ theme), and more videos covering experimental, theoretical and analytical aspects (Figure 4). In addition, more Go8-2 than Go8-1 students reported that the theoretical and experimental coverage of the pre-laboratory exercises was a positive aspect (Figure 2), suggesting that Go8-1 students needed more resources to feel confident, prepared and less anxious in the laboratory.

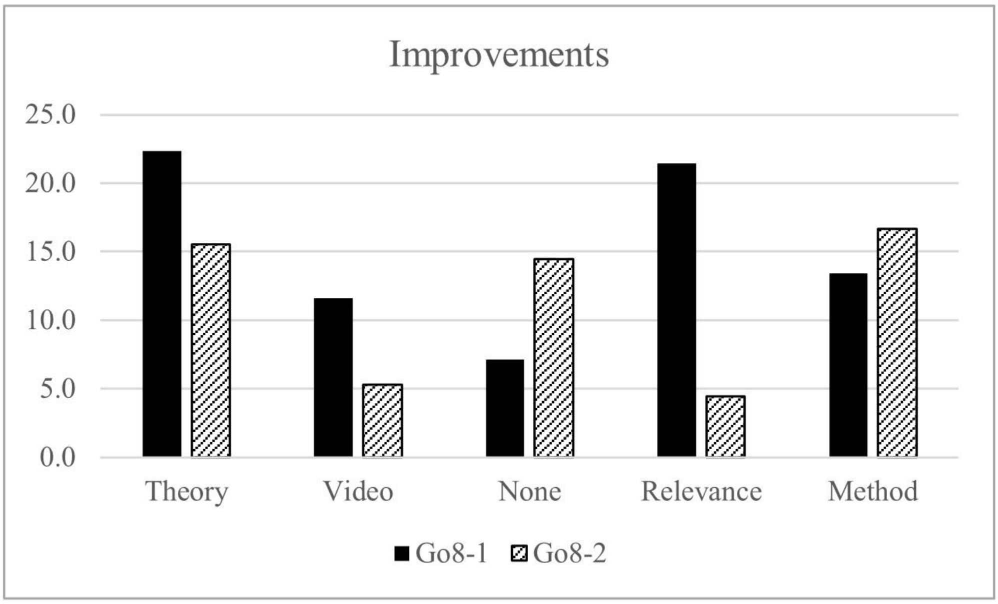

Figure 4: The percentage of students whose open response questions were themed into each category for Question 2: How could the pre-laboratory exercises be changed to improve your preparation for laboratory classes? (Please explain why). Theme definitions are outlined in Table 6.

Equipment Support

There was no statistically significant difference between Go8-1 and Go8-2 students for the Equipment Support factor analysis results (Table 4). This factor represented the need for more support identifying, setting up and using equipment. The majority of students stated they did not need more support in this area, with between 53.1 and 64.2% of students disagreeing or strongly disagreeing to Likert items 2 to 4 (Figure 5). In contrast, 51.2 and 52.8% of students at Go8-1 and Go8-2, respectively, agreed or strongly agreed that the pre-laboratory exercises needed more detail regarding identifying, assembling and/or using laboratory equipment. These seemingly disparate results suggest that students were able to work independently with equipment in the laboratory classes, yet would have liked more out-of-class preparation to support that independence. This finding is backed by the 13.4% of Go8-1 students and 16.7% of Go8-2 students whose responses to 'how could the pre-laboratory exercises be improved?' were themed as 'Method' (Figure 4). A subset of responses in this theme outlined the need for more information on how to carry out the experiment and handle equipment. The 'Video' theme also had similar comments about experimental information, such as "*videos on how to perform specific new techniques/skills would reduce stress/confusion in the lab*" (Participant Go8-2-516), and was noted in 11.6% of Go8-1 and 5.4% of Go8-2 responses. This could reflect the ability of video to portray manual-handling instructions more accurately and efficiently than text-based instruction (Teo et al., 2014).

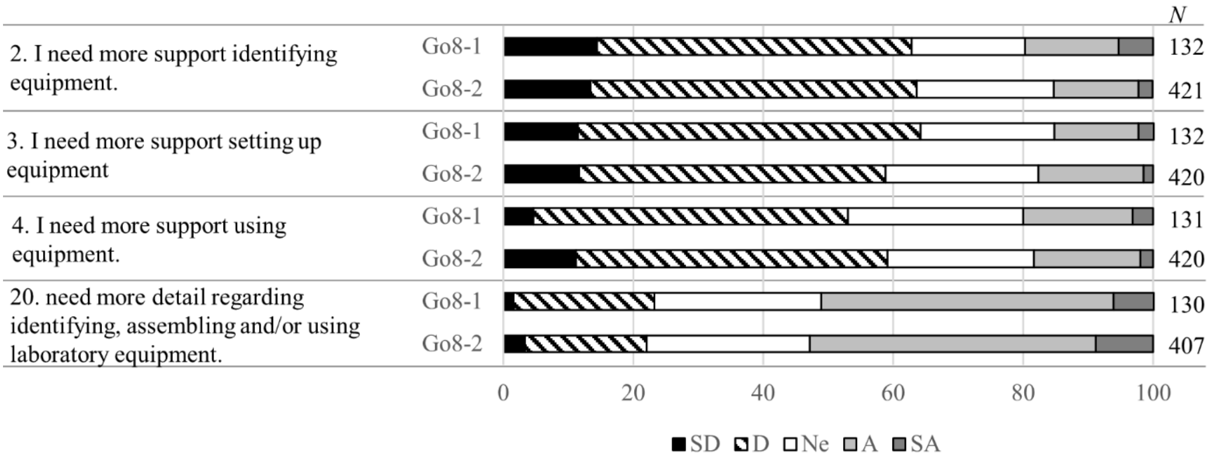

Figure 5: The percentage of student responses for each Likert option for questions that were classified into the Equipment Support factor. Item 20 started with the phrase "The pre-laboratory exercises…". Likert options were strongly disagree (SD), disagree (D), neutral (Ne), agree (A) and strongly agree (SA). ***N*** **number of students responded to each question.**

Likert item 29, 'It is more important that the pre-laboratory exercises teach theory than experimental information,' was inspired by the conflict between van Merrienboer, Kirschner, and Kester (2003), a proponent of 'just-in-time' instruction for procedural information, and the results of an unpublished pilot study of this research that found that students wanted more preparatory resources regarding equipment set-up and use (Scarborough, 2018). This latter finding was also observed in this study, where a subset of student responses to 'which particular aspects of the pre-laboratory exercises were helpful?' that were themed under 'Video' specified that the videos were useful because they showed how equipment was set up and used, and clarified instructions found in the laboratory manuals. Likert item 29 indicated that student preferences for what is taught in pre-laboratory exercises was mixed, with the disagreement, agreement and neutral options receiving approximately a third of the responses each. The results of item 29 emphasised that the background and learning needs of each student are different, and therefore a wide range of learning activities need to be incorporated to take into consideration each students' zone of proximal development (Vygotsky, 1978). In addition, touching upon all aspects of the laboratory class in the pre-laboratory exercise could minimise anchoring bias, whereby students mainly focus on the practical aspects that were covered in the preparatory materials, believing that these are the only aspects that the teaching staff wish them to pay attention to (Winberg & Berg, 2007).

Preferred pre-laboratory exercise

Students were also asked which type of questions in the pre-laboratory quiz best prepared them for laboratory classes. The most frequent responses from Go8-1 students were coded into the 'Calculations', 'Aims', 'Theory' and 'Methods' themes, whilst the most common themes for Go8-2 were 'Safety', 'Methods' and 'Theory' (Figure 6 and Table 7). Students requested calculation questions for preparation, such that they could understand how to do them, and to make calculations completed during or post class easier. One of the most common reasons for stating 'Aims' and 'Methods' questions was to know what to expect in the laboratory. The relationship between 'Aims' and 'Method', and the 'Assessment' was also raised, as well as needing to understand how to undertake the experiment. Students commented that theory was important because "*it is easier … to perform the experiment if I understand the theory first whereas if I don't I have to mindlessly follow instructions*" (Participant Go8-1-35), and "*so that observations can be understood in relation to the theory*" (Participant Go8-1-64). 'Safety' questions were more often referenced by Go8-2 students than Go8-1, likely due to the emphasis of safety and waste disposal in each quiz at Go8-2. Go8-2 students believed that these questions were useful as "*safety is the priority in any chemical experiment we conduct and so properly handling dangerous materials is one of the most important things*" (Participant Go8-2-119).

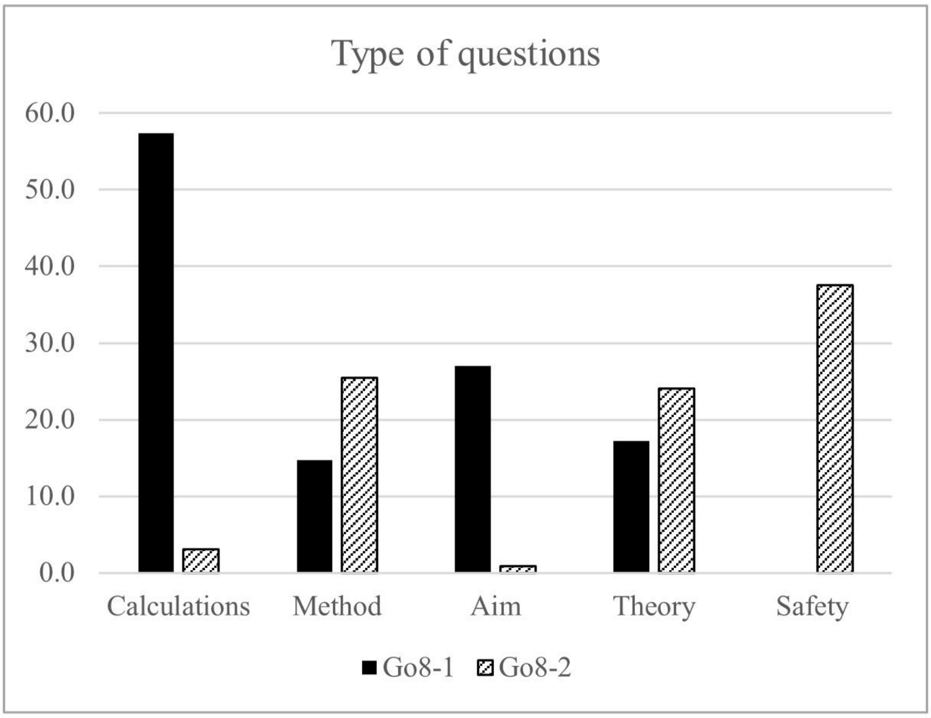

Figure 6: The percentage of students whose open response questions were themed into each category for Question 3: Which type of questions in the pre-laboratory quiz best prepare you for laboratory classes? (Please explain why). Theme definitions are outlined in Table 7.

Table 7: The themes and their definitions, with examples, for the open response question "Which type of questions in the pre-laboratory quiz best prepare you for laboratory classes? (Please explain why)".

Theme	Definition	Example
Aim	Questions about the aim or generating an aim.	"Fill in the blanks of the aim. I always feel [lost] after I read the lab handbook, but the process of find the answer of the aim help me to build the basic concept." (Go8-1-60)
Calculations	Example and practice calculations. Explanations of calculations.	"Calculations. When learning a new calculation in the lab, it slows me down trying to understand & use it for the first time in the lab." (Go8-2-299)
Method	Questions relating to the methods, steps, skills or processes that will be used in the laboratory.	"Specific questions about the steps in each part, such as understanding why such steps are needed to be done." (Go8-2-132)
Safety	Questions relating to safety, risk assessment and waste disposal.	"Safety + how to dispose of materials; ensures these pieces of important info have been remembered." (Go8-2-115)
Theory	Questions relating to theory, concepts, content or understanding.	"Explain the observation ones with the options to choose from so that the observations can be understood in relation to the theory." (Go8-1-64)

Table 8: The themes and their definitions, with examples, for the open response question "Briefly outline an activity that would best prepare you for laboratory classes."

Theme	Definition	Example
Calculation	Example and practice calculations. Explanations of calculations.	"If there are experiments involving calculations, we should do a practice calculation, otherwise I have no clue what I'm doing in class." (Go8-2-355)
Expanded quiz	Incorporate additional elements into the quiz (e.g. more questions and additional activities).	"Being quizzed on why each step is performed." (Go8-2-193) "Creating a flowchart of method." (Go8-1-45)
Method	Which methods, skills and experimental techniques will be used. Being given an expectation of what will happen in class.	"Online videos of steps and techniques that we haven't performed before" (Go8-1-30)
Pre-meet	In person communication with teaching staff.	"Mini lectures that goes through the techniques or theory behind the pracs." (Go8-2-286) "A ten minute summary of the lab during the start of the lab." (Go8-1-72)
Quiz	A quiz of a similar style to those already used or not specified that the quiz is 'expanded' (see expanded quiz).	"The prelab quiz and reading through the lab manual." (Go8-1-52)
Read	Reading the pre-laboratory materials or activities that would require reading.	"Read through the experiment I am going to do in next class from the laboratory handbook" (Go8-2-138) "Some tips in a document for each lab for completing the prac of the week." (Go8-2-127)
Video	A video or an activity that would require a video to be watched.	"Demonstration." (Go8-1-19) "Video explaining prac and relevant questions." (Go8-1-107)

To determine the type of pre-laboratory exercise preferred by students, they were asked to briefly outline an activity that would best prepare them for laboratory classes. A limitation of this question was that student answers were too brief, often simply stating a resource such as "quiz" or "video" with little extrapolation. The most common activity types, from most suggested to least, were watching a 'Video', a 'Quiz', 'Reading', methodological information, an 'Expanded quiz', a pre-laboratory meeting and 'Calculations'. The percentage of responses for each cohort were similar, as shown in Figure 7. 'Video' was the most popular option at both institutions, and students requested a wide range of video content including introductory material, equipment use, experimental methodological details, calculations and data analysis. The next most popular activity was a quiz of a similar style to those currently existing, with 18% of both Go8-1 and Go8-2 suggesting the activity, with 7% of Go8-1 and 13% of Go8-2 students requesting an 'Expanded quiz'. 'Expanded quizzes' incorporated elements not currently existing such as questions relating to learning outcomes, equipment set up and the purposes of specific experimental steps.

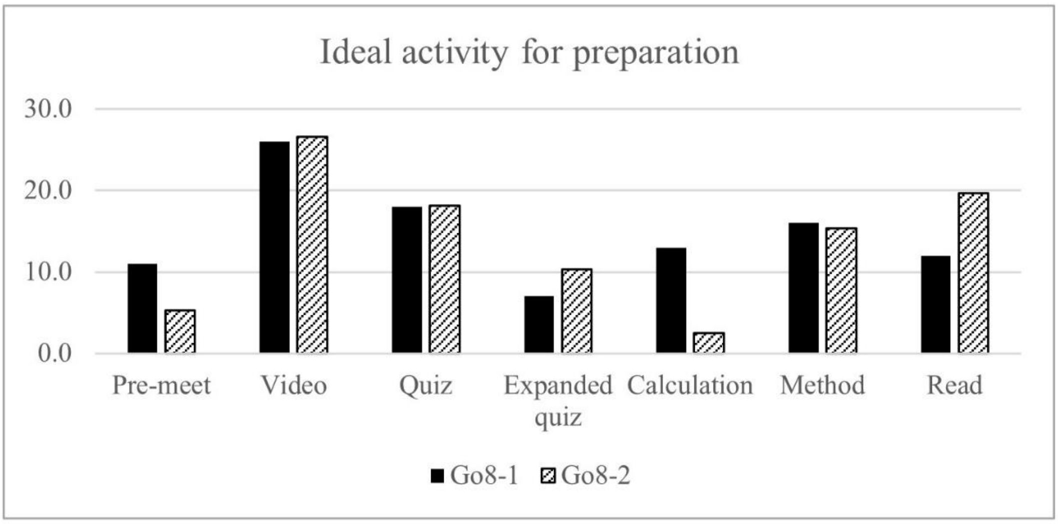

Figure 7: The percentage of students whose open response questions were themed into each category for Question 4: Briefly outline an activity that would best prepare you for laboratory classes. Theme definitions are outlined in Table 8.

Limitations

The first limitation of this study is the low response rate from Go8-1 students. This could be an indicator that the data collected were not representative of the whole cohort, particularly given that the questionnaire was administered during a non-compulsory class.

Additional depth to students' responses would aid this research greatly, this could be achieved via interviews and could form the basis of future studies undertaken in this area. For example, responses to the open response questions indicated that the perceived quality of the pre-laboratory exercises is dependent on what happens in the laboratory class, and how the class is assessed, however no questions were asked relating to these two aspects. Therefore, no conclusions can be made about the relationship between the pre-laboratory exercise, the specific class and the assessment schedule.

Another limitation is the nature of the institutions involved, as both institutions are members of the Australian Go8 system. Students enrolled in these institutions tend to have achieved very high secondary school grades and typically come from less diverse backgrounds. As such, caution is required when generalising the results found here to more diverse student cohorts.

Lastly, the quantitative data generated in this report were ordinal in nature, which is the result of using Likert scales. While checks on the normality of the cohort's responses were undertaken, there is still debate in the literature on the use of parametric tests on non-continuous data. As such, it is possible that the statistical differences are slightly overestimated.

As acknowledged earlier, the differences in the context of the lecture course, laboratory course, and assessment could impact student perceptions of the pre-laboratory exercises. Therefore, the comparison between Go8-1 and Go8-2 must be undertaken with care. Further questioning of students regarding how laboratory course and assessment formats impact laboratory preparedness would allow further conclusions to be drawn on which pre-laboratory activities improve student perceptions of laboratory preparedness.

Conclusions

This study compared student perceptions of pre-laboratory exercises at two Australian institutions. Questionnaires including both Likert-style and open response questions were used to collect student perception data. 141 and 461 questionnaires were returned by students at Go8-1 and Go8-2, respectively. Data were analysed via factor analysis, resulting in factors relating to Performance/Understanding, Personal/Affective aspects and Equipment Support. Go8-1 students were more likely to feel prepared to perform well and understand the content of the laboratory, whilst Go8-2 students were more likely to feel positively towards the laboratory classes. These differences were thought to be due to the Go8-1 pre-laboratory exercise presenting and asking more questions on a wider range of experimental aspects. Another possible reason for differences between the two groups is the way in which the laboratory classes were assessed, however this needs to be confirmed by further study of each cohort. Students from both institutions also expressed that videos were an important component of the pre-laboratory activity.

Implications for practice

Student responses to the Likert and open response questions indicated that pre-laboratory exercises should touch upon all aspects of the experiment, that is the background, theory, aims, methods, equipment use and set up, calculations and data analysis. Videos, written material and quizzes were the most commonly suggested components of ideal pre-laboratory activities. Scaffolding needs to be improved such that students understand why the pre-laboratory activities are important for their success in the laboratory.

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References

Agustian, H. Y., & Seery, M. K. (2017). Reasserting the role of pre-laboratory activities in chemistry education: a proposed framework for their design. *Chemistry Education Research and Practice, 18*(4), 518-532.

Altowaiji, S., Haddadin, R., Campos, P., Sorn, S., Gonzalez, L., Villafañe, S. M., & Groves, M. N. (2021). Measuring the effectiveness of online preparation videos and questions in the second semester general chemistry laboratory. *Chemistry Education Research and Practice,* 22(3), 616-625.

Blackburn, R. A. R., Villa-Marcos, B., & Williams, D. P. (2019). Preparing students for practical sessions using laboratory simulation software. *Journal of Chemical Education, 96*(1), 153-158.

Boone Jr, H. N., & Boone, D. A. (2012). Analysing Likert data. *Journal of Extension, 50*(2), 2TOT2.

Chaytor, J. L., Mughalaq, M. A., & Butler, H. (2017). Development and use of online prelaboratory activities in organic chemistry to improve students' laboratory experience. *Journal of Chemical Education, 94*(7), 859-866.

Chittleborough, G., & Treagust, D. (2008). Correct interpretation of chemical diagrams requires transformation from one level of representation to another. *Research in Science Education, 38,* 463-482.

Chittleborough, G. D., Mocerino, M., & Treagust, D. F. (2007). Achieving greater feedback and flexibility using online pre-laboratory exercises with non-major chemistry students. *Journal of Chemical Education, 84*(5), 884-888.

Clemons, T. D., Fouché, L., Rummey, C., Lopez, R. E., & Spagnoli, D. (2019). Introducing the first year laboratory to undergraduate chemistry students with an interactive 360 experience. *Journal of Chemical Education, 96*(7), 1491-1496.

Dalgarno, B., Bishop, A. G., Adlong, W., & Bedgood Jr., D. R. (2009). Effectiveness of a virtual laboratory as a preparatory resource for distance education chemistry students. *Computers & Education, 53*(3), 853-865.

Davidowitz, B., & Rollnick, M. (2001). Effectiveness of flow diagrams as a strategy for learning in laboratories. *Australian Journal of Education in Chemistry, 57,* 18-24.

George-Williams, S. R., Ziebell, A. L., Kitson, R. R. A., Coppo, P., Thompson, C. D., & Overton, T. L. (2018). 'What do you think the aims of doing a practical chemistry course are?' A comparison of the views of students and teaching staff across three universities. *Chemistry Education Research and Practice, 19*(2), 463-473.

Gregory, S., & Di Trapani, G. (2012). A blended learning approach to laboratory preparation. *International Journal of Innovation in Science and Mathematics Eduation, 20*(1), 56-70.

Hayes, A. F., & Krippendorff, K. (2007). Answering the call for a standard reliability measure for coding data. *Communication Methods and Measures, 1*(1), 77-89.

Hunter, C., Wardell, S., & Wilkins, H. (2000). Introducing first-year students to some skills of investigatory laboratory work. *University Chemistry Education, 4*(1), 14-17.

Johnstone, A. H. (1997). Chemistry teaching - science or alchemy? *Journal of Chemical Education, 74*(3), 262-268.

Johnstone, A. H. (2006). Chemical education research in Glasgow in perspective. *Chemistry Education Research and Practice, 7*(2), 49-63.

Jolley, D. F., Wilson, S. R., Kelso, C., O'Brien, G., & Mason, C. E. (2016). Analytical thinking, analytical action: Using prelab video demonstrations and e-quizzes to improve undergraduate preparedness for analytical chemistry practical classes. *Journal of Chemical Education, 93*(11), 1855-1862.

Kennephohl, D. (2001). Using computer simulations to supplement teaching laboratories in chemistry for distance delivery. *International Journal of E-Learning & Distance Education, 16*(2), 58-65.

Krippendorff, K. (2004). Reliability in content analysis: Some common misconceptions and recommendations. *Human Communication Research, 30*(3), 411-433.

Mercer-Chalmers, J. D., Goodfellow, C. L., & Price, G. J. (2004). Using a VLE to enhance a foundation chemistry laboratory. *CAL-laborate, 12,* 14-18.

Moozeh, K., Farmer, J., Tihanyi, D., Nadar, T., & Evans, G. J. (2019). A prelaboratory framework toward integrating theory and utility value with laboratories: Student perceptions on learning and motivation. *Journal of Chemical Education, 96*(8), 1548-1557.

Nadelson, L. S., Scaggs, J., Sheffield, C., & McDougal, O. M. (2015). Integration of video-based demonstrations to prepare students for the organic chemistry laboratory. *Journal of Science Education and Technology, 24,* 476-783.

Nicholls, B. S. (1999). Pre-laboratory support using dedicated software. *University Chemistry Education, 3*(1), 22-27.

Reid, N., & Shah, I. (2007). The role of laboratory work in university chemistry. *Chemistry Education Research and Practice, 8*(2), 172-185.

Rodgers, T. L., Cheema, N., Vasanth, S., Jamshed, A., Alfutimie, A., & Scully, P. J. (2020). Developing pre-laboratory videos for enhancing student preparedness. *European Journal of Engineering Education, 45*(2), 292-304.

Rollnick, M., Zwane, S., Staskun, M., Lotz, S., & Green, G. (2001). Improving pre-laboratory preparation of first year university chemistry students. *International Journal of Science Education, 23*(10), 1053-1071.

Sarmouk, C., Ingram, M. J., Read, C., Curdy, M. E., Spall, E., Farlow, A., . . . Patel, B. A. (2020). Pre-laboratory online learning resources improves preparedness and performance in pharmaceutical sciences practical classes. *Innovations in Education and Teaching International, 57*(4), 460-471.

Scarborough, D. L. A. (2018). *Student perceptions of pre-laboratory exercises in first-year undergraduate chemistry* (Unpublished masters thesis). University of New England, Australia.

Schmid, S., & Yeung, A. (2005). *The influence of a pre-laboratory work module on student performance in the first year chemistry laboratory*. Paper presented at the HERDSA, Sydney, Australia.

Spagnoli, D., Wong, L., Maisey, S., & Clemons, T. D. (2017). Prepare, Do, Review: a model used to reduce the negative feelings towards laboratory classes in an introductory chemistry undergraduate unit. *Chemistry Education Research and Practice, 18*(1), 26-44.

Stieff, M., Werner, S. M., Fink, B., & Meador, D. (2018) Online prelaboratory videos improve student performance in the general chemistry laboratory. *Journal of Chemical Education, 95*(8), 1260-1266.

Szteinberg, G. A., & Weaver, G. C. (2013). Participants' reflections two and three years after an introductory chemistry course-embedded research experience. *Chemistry Education Research and Practice, 14*(1), 23-35.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using Multivariate Statistics* (Sixth Edition ed.). New Jersey, United States of America: Pearson.

Teo, T. W., Tan, K. C. D., Yan, Y. K., Teo, Y. C., & Yeo, L. W. (2014). How flip teaching supports undergraduate chemistry laboratory learning. *Chemistry Education Research and Practice, 15*(4), 550-567.

van Merrienboer, J. J. G., Kirschner, P. A., & Kester, L. (2003). Taking the load off a learner's mind: Instructional design for complex learning. *Educational Psycologist, 38*(1), 5-13.

Veiga, N., Luzardo, F., Irving, K., Rodríguez-Ayán, M. N., & Torres, J. (2019). Online pre-laboratory tools for first-year undergraduate chemistry course in Uruguay: student preferences and implications on student performance. *Chemistry Education Research and Practice, 20*(1), 229-245.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.). Cambridge, MA, USA: Harvard University Press.

Whittle, S. R., & Bickerdike, S. R. (2015). Online preparation resources help first-year students to benefit from practical classes. *Journal of Biological Education, 49*(2), 139-149.

Winberg, T. M., & Berg, C. A. R. (2007). Students' cognitive focus during a chemistry laboratory exercise: Effects of a computer-simulated prelab. *Journal of Research in Science Teaching, 44*(8), 1108-1133.