Impact of Online Preparation Modules on Students' Engagement and Interactions in Face-to-Face Fluid Mechanics Laboratories

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Abstract

The transformation of laboratory activities to better embed the development of essential personal attributes and the attainment of specific learning outcomes in the engineering curriculum has been supported by the integration of online preparation modules. Beyond the widely demonstrated effectiveness of multimedia pre-laboratory activities in strengthening students' engagement and preparedness for the execution of experimental tasks, this study also focuses on the effect of these online modules on student-student and student-instructor interactions in face-to-face fluid mechanics laboratories. Survey data show that students with a mid-level of academic performance were more likely to adopt the new resources but that most students perceived them as a valuable complement to, or replacement for, the traditional instruction sheet. While students' self-assurance in conducting the laboratory tasks and appreciation of the instructor's support appear unaffected by the completion of the modules, observations suggest these modules can strengthen students' autonomy and engagement within their group during the conduct of the laboratory activities. Indeed, the introduction of the modules appears to facilitate a transition of the instructor's role from directing the laboratory to guiding students in peer-learning.

Introduction

Many Australian universities have embarked on developing online and blended learning approaches to increase student engagement and support the diverse cohorts in large enrolment undergraduate units. Innovative multimedia tools have been implemented to enable more flexible study environments, enrich the learning experience, and sustain students' motivation. Indeed, online preparation modules have been shown to be effective for increasing students' engagement and performance in lectures (Hill, Sharma, & Xu, 2017) and laboratory classes (Mellefont & Fei, 2016). Flipped-classroom models designed to facilitate the understanding of fundamental concepts and the preparation for hands-on laboratory-based activities (Brophy, Magana, & Strachan, 2013; Paetkau, Bissonnette, & Taylor, 2013) often make use of simulations and video demonstrations, which are delivered asynchronously and available to students at any time (Cresswell, Loughlin, Coster, & Green, 2019). These more versatile online resources can therefore be used by students to prepare for the experimental work conducted in face-to-face laboratories but also as support and review tools.

Laboratory work is an essential element of undergraduate engineering education, responding to the need for exposure to equipment and procedures, and offering a collaborative environment to conduct open-ended activities. The questioning of the function of laboratory components in engineering programs (Feisel & Rosa, 2005) has led to an evolution in the design and assessment of the experimental activities conducted by students to better reflect clear learning outcomes focussing not only on technical skills but also on teamwork, communication, and creativity. Professional bodies, like *Engineers Australia*, have also driven this transformation with the establishment of explicit graduate competencies (Lal, et al., 2020a) and the promotion of activities related to emergent themes such as safety and sustainability.

The quality of instruction sheets can have a significant impact on students' self-direction and satisfaction in laboratory classes. However, these paper-based documents can appear unrepresentative of the real experiments to some students, particularly those with lower academic abilities (Lal, et al., 2020). Online modules have been proposed to offer more engaging resources mostly targeting the understanding of underlying theory, operating procedures, and safety (Huntula, Sharma, Johnston, & Chitaree, 2011). The introduction of pre-laboratory modules including videos and simulations have been shown to improve students' preparedness (Gregory & Di Trapani, 2012) and reinforce their motivation (Moozeh, Farmer, Tihanyi, Nadar, & Evans, 2019). However, the positive outcomes from the use of multimedia materials can be linked to high costs, from the initial implementation through to the regular updates required (George, 2001). Careful consideration and review of the objectives therefore appear crucial in the design of pre-laboratory activities (Agustian & Seery, 2017).

While students' and instructors' respective perceptions of the effectiveness of pre-laboratory modules have been examined (Kirkup, Varadharajan, & Braun, 2016), their interactions remain largely unexplored (Wei, et al., 2019). Indeed, most analyses have been focussed on the benefits produced by new engaging materials for the execution of experimental tasks, i.e. student-equipment interactions. However, student-student and student-instructor interactions have been shown to play a significant part in the achievement of more comprehensive laboratory-learning outcomes (Lal, et al., 2020a). This suggests that changes in the role of the instructor and in the behaviour of students engendered by new preparation resources should be further investigated for laboratory classes (Jones & Edwards, 2010) and, more broadly, for the elaboration of learning strategies in group activities (Tronson & Ross, 2004).

Purpose of the Study

The emergence of blended learning environments in STEM university degrees has been accompanied by the deployment of pre-laboratory online modules mostly aiming to facilitate students' awareness of technical procedures and safety precautions (Huntula et al., 2011). The present study focuses on how students received online preparation modules and the significance of their effects on their conduct of the face-to-face fluid-mechanics laboratory work, considering not only the technical performance of students, but also the student-group dynamics that occur during the laboratory work as reported by the students and observed by the laboratory instructor (also termed a laboratory demonstrator). The following research questions (RQs) are specifically examined:

(RQ1) Adoption: What proportion of students (voluntarily) take up the opportunity to use the online modules as preparation for the laboratory and does such take-up correlate with academic performance?

(RQ2) Perception: Are students satisfied with the quality of the online modules and do they regard them as a potential replacement for the traditional paper-based laboratory-instruction sheet?

(RQ3) Execution: Does the use of the online modules improve students' self-assurance in conducting the required laboratory activities and enhance their group work?

(RQ4) Interactions: What effects of the online modules on students' behaviours and needs in conducting the laboratory work are observed by an instructor?

Methodology

Context

This study was conducted in an Australian university's second-year undergraduate fluid mechanics unit (sometimes called a course or a module) delivered to Civil, Mechanical, Chemical, Petroleum, Mining and Metallurgy Engineering students on the main Australian campus and three offshore campuses. The students had already undertaken laboratory work in their first-year curriculum but without the aid of online preparation modules. Alongside their lecture and tutorial learning, this unit includes two 2-hour laboratory sessions, during which students conduct three experiments (two during the first session and one during the second session) in small groups to observe and analyse different fluid phenomena. Due to the large number (approximately 400 on the Australian campuses) of enrolled students in this cross-disciplinary unit and the limited access to experimental facilities, many students might undertake the two experiments of the first laboratory session before having covered the theoretical treatment of the phenomena in the lectures. The first laboratory, assessed in-class (Lal, et al., 2017), is therefore based on discovery learning designed to practise carrying out experimental procedures, collect appropriate data, analyse these data, and then discuss the results while making engineering judgements about the quality of the data.

Prior to the developments described in this study, students' preparation for the first laboratory relied on a brief document detailing the instructions and expectations, and a demonstration of the experimental work presented by the instructor at the beginning of each session. However, observations (Lal, et al., 2017) and student feedback showed that some students had difficulties performing all the required tasks during the laboratory session and therefore did not have sufficient time to reflect on their practice. This was thought to arise from students' limited prior exposure to experimental techniques and the specialised laboratory equipment used.

Accordingly, interactive online modules based on video demonstrations were developed to encourage students to familiarise themselves with the equipment and procedures, and therefore spend less time learning how to run the experiments during the time-limited session and thereby increase their focus on data collection, analysis and reflection on their meaning. These tools were also designed to interest and engage students prior to the laboratory as well as ensuring consistency of the information provided during demonstrations of equipment conducted by several staff across multiple campuses. Overall, they aspired to promote a more reflective learning experience for students facilitated by the instructors during the face-to-face laboratory.

Online-Preparation Modules

An interactive module was developed and implemented for each experiment conducted during a student's laboratory session. Both modules had about 12 interactive pages and the same structure, as illustrated in Figure 1, designed to encourage students' questioning (Huntula et al., 2011), provide clear expectations to them with detailed information about the context, equipment and procedures (Lal, et al., 2020; Van De Heyde & Siebrits, 2019), and offer a formative assessment on key aspects of the experiments (Moozeh et al., 2019). In brief, each module comprised (see Figure 1)

(a) an introductory video related to the topic of the experiment with a questioning prompt,
(b) a quiz on prior knowledge that students should have acquired in a previous unit,
(c) a short summary of the main fluid-mechanics concepts required to analyse the system,
(d) video presentations of the equipment embedded in interactive pages,
(e) video presentations of the procedure steps embedded in interactive pages, and
(f) a quiz on critical steps of the experiment, which can lead to measurement errors.

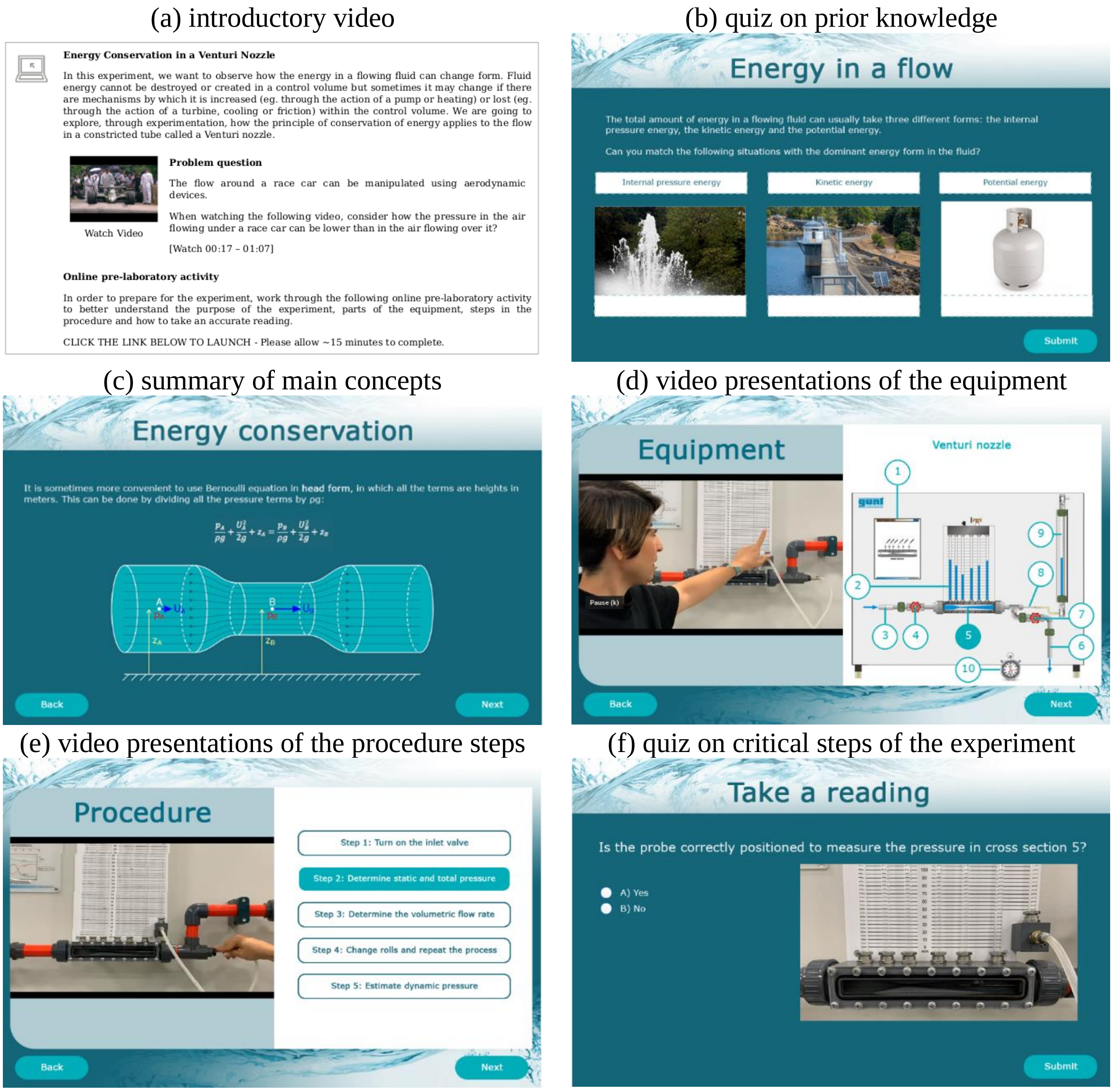

Figure 1: Example pages of online preparation modules

The modules were available and advertised in the first week of the semester through the Learning Management System (LMS). Students had unrestricted access (time frame and number of attempts) to the modules which were introduced as additional preparatory materials since their completion, before the laboratory session, was not compulsory. The completion of each module was expected to take about 15 minutes.

LMS Data Analytics

Since both modules were deployed as SCORM (Sharable Content Object Reference Model) objects, access and interactions with the different parts of the packages could be monitored. Data recorded for individual students included the time and duration of module completions, and the answers to the quizzes. Students' marks for the different assessments of this unit were also collected to segment the cohort into three groups based on academic achievement. According to their final mark in the unit (maximum 100), students were identified as:

- High-performing (Hi-Perf): unit final mark above 80,
- Medium-performing (Med-Perf): unit final mark between 60 and 80, or
- Low-performing (Low-Perf): unit final mark below 60.

Student Survey

The survey tool developed to address the research questions RQ1-RQ3 in this study were articulated around the adoption and impact of the online preparation modules in relation to the preparation, execution, perception and satisfaction of the laboratory activities. The questions presented to students in the survey form completed at the end of the laboratory session focused on four main aspects:

- the resources used before attending the laboratory,
- the relevance of the online modules as additional resources to the traditional instruction sheet in the preparation of the different parts of the laboratory work,
- impressions of the conduct of the laboratory work, and
- satisfaction with the different components of the online modules.

To collect qualitative data, students were also invited to suggest improvements regarding the overview of theoretical concepts included in the online modules, the presentations of the apparatus and the procedure steps, the explanations on data collection and results analysis, and the overall design of the modules.

Instructor Survey

An instructor (laboratory demonstrator) with several years' experience of supervising the unit's laboratory activities was also surveyed in order to answer RQ4. The questionnaire was designed by the research team to collect the instructor's observations during the laboratory sessions and their perception of students' ways of working as compared to previous years' cohorts (Peteroy-Kelly, 2010). The questions targeted criteria related to students' preparedness, their technical execution, and their levels of interactions, support required and reflection. The semi-quantitative results emerging from the responses provided a different perspective, from that of the students, on the impact of the online preparation modules on the laboratory work, and a better insight to the changes in student-student and student-instructor interactions that the modules had occasioned.

Results

Study cohort

From the 170 students who attended a face-to-face session[1] for the first laboratory on the main Australian campus, 136 agreed to participate to the study and provided valid survey responses. Ethics approval was obtained before conducting the study presented in this paper. A detailed breakdown of the 136 respondents in shown in Table 1. The majority of survey respondents (75 of 136, i.e. 55%) were students in the medium-performing category, while 35% (47 of 136) were in the high-performing category, and 10% (14 of 136) were in the low-performing category. These proportions are generally consistent with the overall final-grade distribution for the unit's total cohort across the multiple campuses at which the unit is delivered.

Students' Adoption of Online Preparation Modules (RQ1)

Data collected from the LMS shown in Table 1 indicate that most survey respondents (82%) completed the online module for the first experiment but only 60% of the survey cohort completed the online module for the second experiment. Possible explanations for this disparity are that some students might have completed the pre-lab online modules in groups – therefore not undertaking the task with their individual LMS account – and confusion with the numbering

[1] About half of the face-to-face sessions for the first laboratory were substituted with an online alternative following the introduction of restrictions linked to the Covid-19 pandemic, so that only half of the unit cohort on the main Australian campus had the opportunity to participate in the study.

of the activities; some students thinking that the second module was for the second laboratory, not the second experiment of the first laboratory. In the following, completion recorded in the LMS is denoted as *effective* completion, since it is a more objective measure of student interactions with the online modules, as discussed in the third paragraph of this sub-section.

Table 1: Survey and effective (data retrieved from LMS) preparation module completion by student performance category (p<0.05 indicates a statistically significant link between module completion and performance category) – This data also informs the number of responses on which the results in Figures 2-7 are based.

Completion	Hi-Perf		Med-Perf		Low-Perf		Total		χ^2 test
	N	%	N	%	N	%	N	%	p-value
Survey	47	100%	75	100%	14	100%	136	100%	N/A
Module 1	37	79%	65	87%	10	71%	112	82%	0.281
Module 2	28	60%	50	67%	4	29%	82	60%	0.028
Both Modules (1 and 2)	27	57%	50	67%	3	21%	80	59%	0.021
Only One Module (1 or 2)	11	23%	15	20%	8	57%	34	25%	
No Module	9	19%	10	13%	3	21%	22	16%	

Most students made use of the optional modules, since only 16% of the survey respondents did not make any attempt to access them. A $\chi 2$ test revealed a statistically significant relationship between the students' overall performance in the unit and completion of the modules. The category with the largest number of students also has the highest effective completion rate, with 87% of the medium-performing students completing at least one of the modules. This shows that average students were more likely to take the opportunity offered by additional resources to prepare for the laboratory (Lal, et al., 2020). However, students in the low-performing category appeared to be less likely to fully engage with the optional online materials, since their effective completion rate for both modules (21%) was significantly lower than for the other two categories.

Student-survey responses are shown in Figure 2 and Figure 3. When asked about the unit materials used for the laboratory preparation prior to the face-to-face session, almost all respondents (96% – see Figure 2) answered that they had read the instruction sheet traditionally used for this activity. However, fewer students reported that they had read the relevant lecture materials (86%) and completed the optional pre-lab online modules (77%). This indicates that about 1 in 7 students might rely only on direct instructions in their study and do not take initiatives to better prepare themselves for their laboratory learning. This type of behaviour is more likely linked to low-performing students (Lal, et al., 2020), as clearly seen in Figure 3 where the overall data of Figure 2 have been separated out by performance category. Indeed, while the proportion of students reading the paper-based instruction sheet before attending the laboratory session is uniform across the performance categories, the number of positive answers from low-performing students for other preparation materials is lower than that of the other categories. A $\chi 2$ test indicated that the association between the students' answer and performance category was only statistically significant for the use of relevant lecture materials. The comparison suggests that medium-performing students might be the most engaged group, making use of all the unit materials available. Furthermore, different results emerge from the survey answers in Figure 3 and the LMS data that yielded Table 1 for the completion of the online modules across the different performance categories and overall. These discrepancies are within reasonable level of uncertainty (about 10%) for the survey method and highlight a certain degree of bias in the respondents' answers (Porter, 2011; Standish & Umbach, 2019).

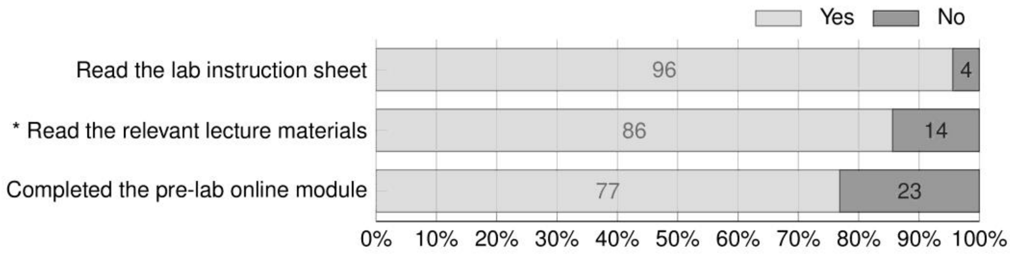

Figure 2: Percentage of survey answers on preparation before laboratory attendance

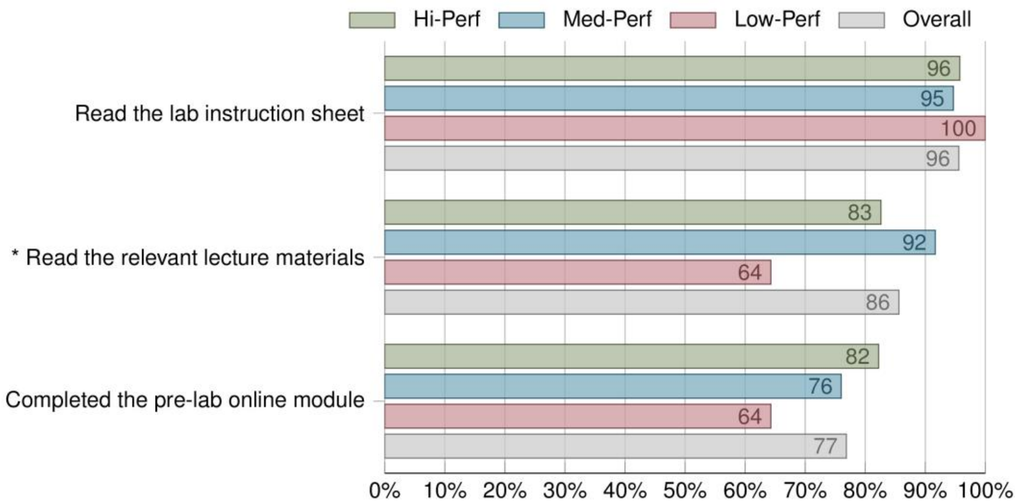

Figure 3: Percentage of survey answers (Answer: Yes) on preparation before laboratory attendance by student performance category - * indicates a statistically significant link between students' answer and performance category ($p<0.05$)

Students' Perception of and Satisfaction with the Online Modules (RQ2)

While the online modules implemented comprise introductory parts to stimulate discovery learning and provide some context for the two experiments, the principal objective of their design was the integration of video demonstrations of the experimental equipment and procedures in an interactive interface. These modules were therefore conceived as more engaging tools than the paper-based instruction sheet, aiming to better prepare students for the execution of the experimental tasks in the time-limited laboratory session. The survey results shown in Figure 4 confirm that most of the students who completed both modules found the modules more useful than the instruction sheet for the technical parts of the face-to-face laboratory, including identification of the parts of the apparatus (84%), use of the equipment (81%) and experimental procedures (71%). The introductory parts of the modules appeared to be slightly less effective since only 59% of the cohort perceived the modules as more helpful than the instruction sheet to understand the context and applications of the experimental work, 64% to understand the physical phenomena at play, and 49% to understand the objectives of the laboratory work. This indicates that paper-based instructional documents still play a critical role in students' learning experience, but that diverse resources can be used to offer alternative ways of presenting concepts and engage a broader audience (Gregory & Di Trapani, 2012; Van De Heyde & Siebrits, 2019; Veiga, Luzardo, Irving, Rodríguez-Ayán, & Torres, 2019).

Since the criteria used to assess the work of each group during the laboratory sessions were focused on the collection, analysis and interpretation of experimental data (labelled "Results and Analysis" in Figure 4), the resources were designed to promote self- and peer-learning for these aspects of the laboratory work. Minimal details of these tasks were therefore provided in the instruction sheet while the online modules only briefly alluded to the processing of the data and the discussion of the results. Thus, as expected, about two thirds of the students who completed both modules preferred the instruction sheet to know how to process (63%) and interpret (60%) the data, and only 8% thought that neither mode was useful to understand how to interpret the results. A more equal divide appeared in students' choice for data collection, with similar levels of preference for the online modules (51%) and the paper-based sheet (47%). This result highlights again the worth of offering multiple media to students.

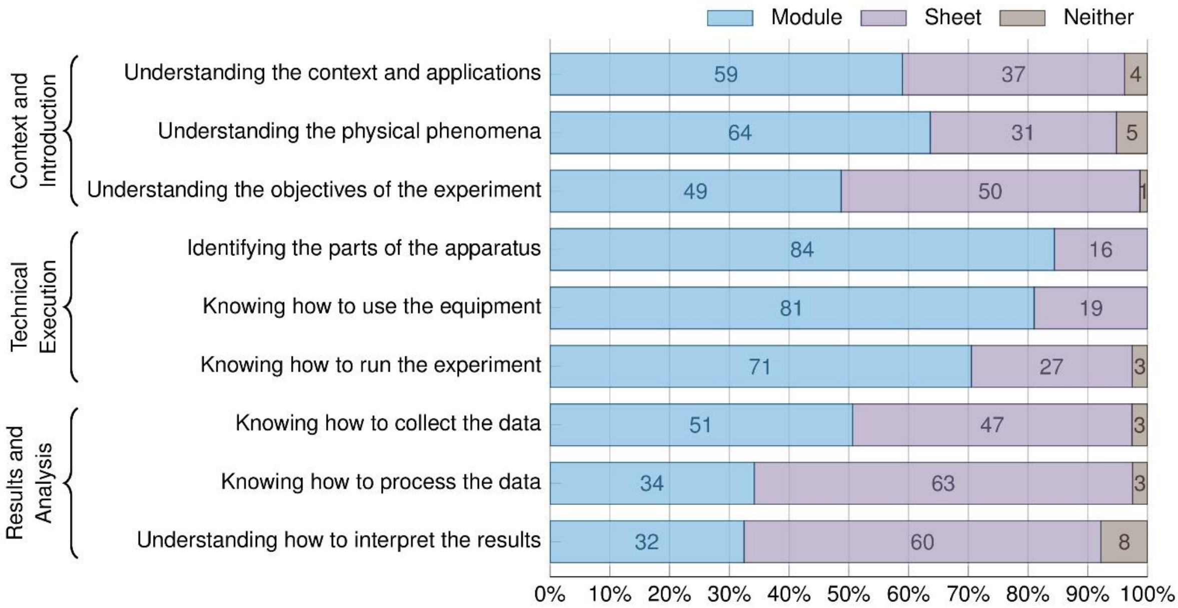

Figure 4: Percentage of survey answers on preferred material (Survey participants who effectively completed both modules)

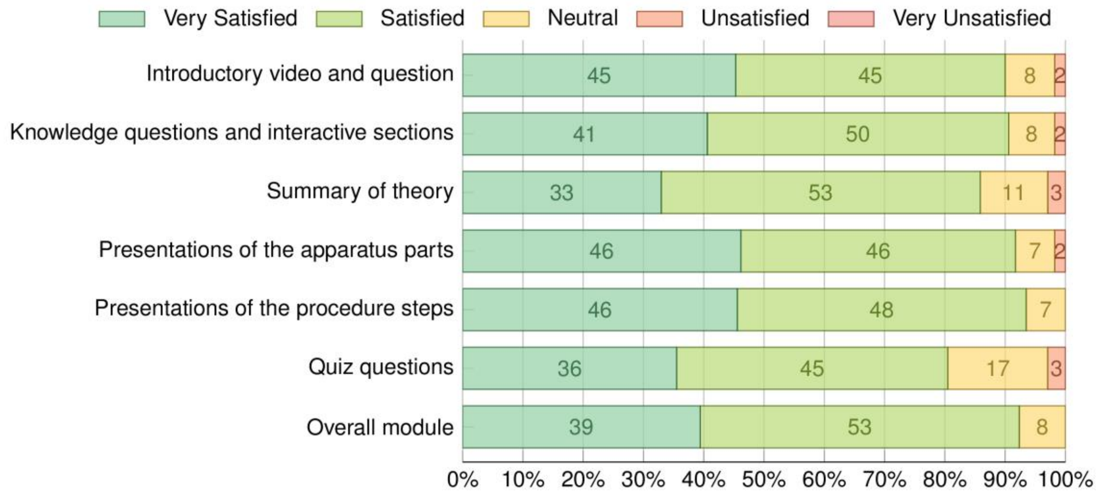

Figure 5: Percentage of survey answers on module satisfaction

Students generally appreciated the quality of the online modules. As shown in Figure 5, about 90% of the students who completed both modules were satisfied or very satisfied with most parts of the modules and overall. The lowest satisfaction rate, although 81%, was obtained for the quiz questions. Indeed, qualitative feedback received in the survey forms (open-ended questions asking for suggestions) revealed that some students would prefer additional and/or more complex questions. Another issue commonly raised was the repetitive character of the quizzes arising from multiple attempts of the modules. Their linear structure forced students to go through all the interactive pages and prevented them from directly accessing a particular part of interest. Nevertheless, the two parts that were the main targets and received the most consideration during the conception of the modules, i.e. the video presentations of the apparatus parts and procedure steps, were also the most highly regarded, with 46% of students very satisfied with both of them.

Impact of Online Modules on Students' Execution of the Experimental Work (RQ3)

Figure 6 and Figure 7 present data on students' experience of conducting the face-to-face laboratory work, for the entire cohort and segmented by module completion, respectively. Overall, there is a clear difference between the responses for the first two items and the following five items, for which agreement is at a much higher level. Indeed, Figure 6 shows that only about half of the survey cohort agreed or strongly agreed that they could start the experiment (48%) or run the experiment (49%) without the help of the demonstrator. This reveals that the pre-laboratory modules cannot completely substitute the initial demonstration done by the instructor and their support during the laboratory session. Nonetheless, most survey respondents (92%) felt comfortable collaborating with other students to conduct the laboratory work. Thus, the effects of the online modules on the self-assurance of individual students appear to be limited and somewhat contrasting. As shown, in Figure 7, the students who completed at least one of the two modules felt slightly more confident to work without interventions from the instructor, but slightly less confident to engage with their group members than students who did not complete either module. These results seem to indicate that students, well-prepared or not, generally value the supervision and assistance of the instructor (Kirkup, Varadharajan, & Braun, 2016), but also rely on their peers to perform the required tasks more effectively (Wei, et al., 2018).

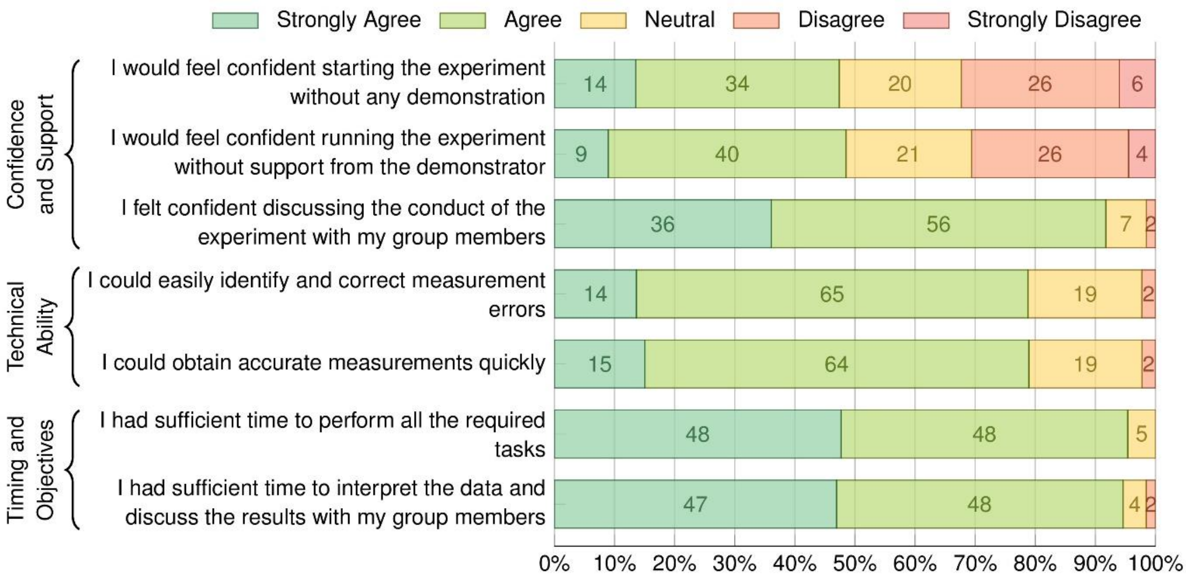

Figure 6: Percentage of survey answers on experience during laboratory activities

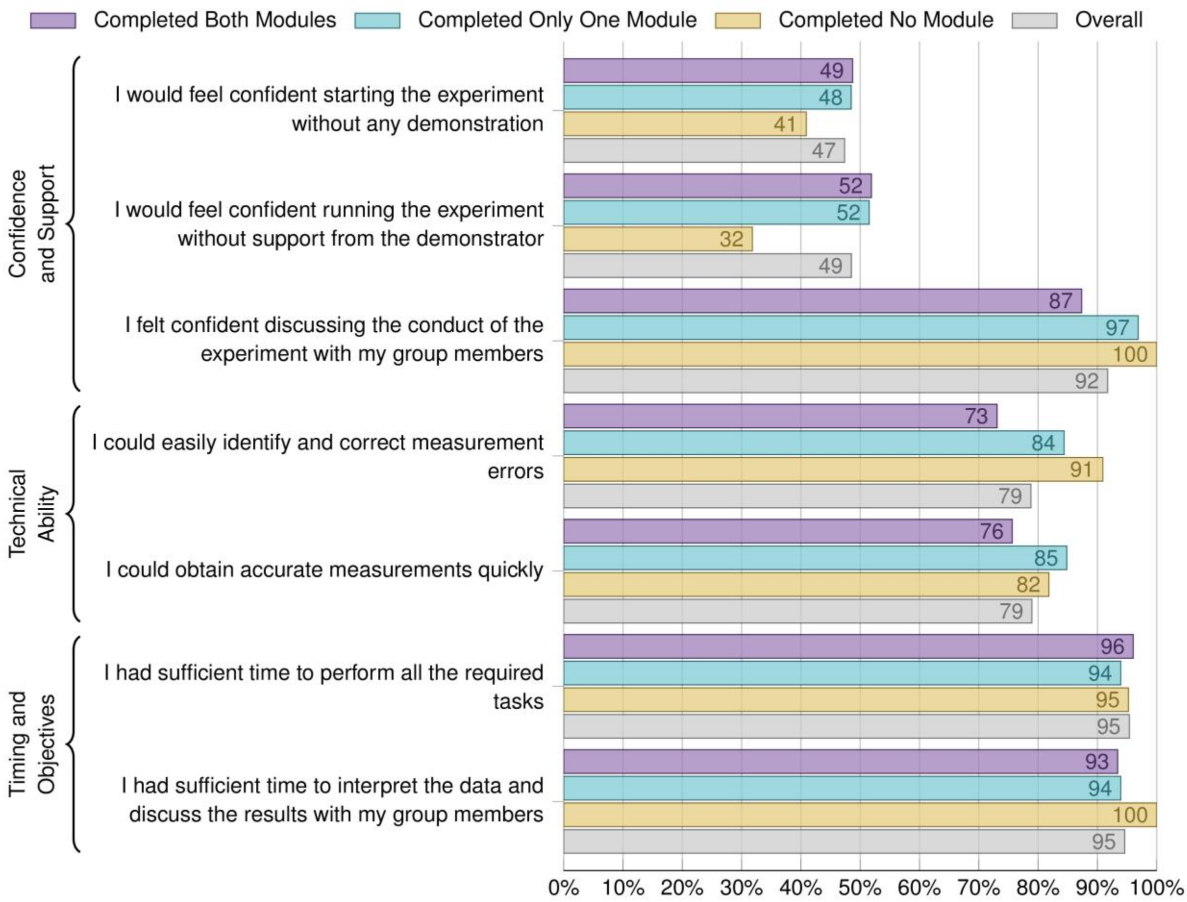

Figure 7: Percentage of survey answers (Answer: Strongly Agree or Agree) on experience during laboratory activities by effective module completion

The final four items in Figure 6 and Figure 7 concern students' perceptions of their conduct in the laboratory work. In the technical aspects, 79% of the survey cohort agreed or strongly agreed that they could obtain accurate measurements quickly, and easily identify and correct measurement errors, as shown in Figure 6. Regarding their management of the session, even higher rates of agreement were reported with 95% of students answering that they had sufficient time to carry out all the required tasks, interpret the data and discuss the results. Overall, students reported that they could generally achieve the main objectives of the first laboratory class, designed for discovery learning and to provide practice in conducting experimental work (Lal, et al., 2017).

The comparison presented in Figure 7 shows that students who completed both online modules were less positive about their execution of the technical tasks than students with a partial completion or no completion of the modules. The differences in percentage agreement on the capacity to identify and correct measurement errors, and to obtain accurate measurements suggest that, although better prepared, students who completed both online modules were less confident about carrying out the experimental work. We conjecture that these arguably more diligent students have greater self-awareness of their abilities and may be more critical of their performance. Despite this unanticipated result (Nadelson, Scaggs, Sheffield, & McDougal, 2015; Rodgers, et al., 2019), the relatively small magnitude of these differences indicates that the modules might have a limited impact on the technical performance of individual students in their conduct of the laboratory work. Indeed, Figure 7 shows that the percentage agreement on the time sufficiency to achieve the laboratory objectives is almost independent of the level of module completion. Furthermore, a $\chi 2$ test showed that no significant link could be established between students' completion of the modules and answers ($p>0.05$ for all items shown in Figure 7).

Table 2: Student statistics and observations (relative to previous years) of instructor in laboratory sessions

Sessions	A	B	C	D	E	F	G	H	I	J
Completed Survey	11	9	11	5	5	12	9	7	10	9
Completed Both Modules (1 and 2)	3	4	6	3	3	8	6	5	8	8
Completed Only One Module (1 or 2)	5	1	4	1	2	3	2	2	1	1
Completed No Module	3	4	1	1	0	1	1	0	1	0
% Completed Both Modules / Completed Survey	27	44	54	60	60	66	66	71	80	88
Hi-Perf	3	1	2	0	3	7	3	2	3	1
Med-Perf	7	7	8	4	1	4	4	4	7	7
Low-Perf	1	1	1	1	1	1	2	1	0	1
Students asked less technical questions before starting the experiment	N	N	A	A	N	A	A	A	A	N
Students needed less support to run the experiment	D	A	A	A	A	SA	SA	SA	A	A
Students interacted/discussed more the conduct of the experiment within their group	A	A	A	A	SA	N	SA	SA	A	A
Students could identify and correct more easily measurement errors by themselves	N	A	A	SA	SA	A	A	SA	A	A
Students could obtain accurate results more quickly	N	N	N	A	A	A	N	A	N	N
Students had sufficient time to perform all the required tasks	N	N	N	N	N	N	N	N	N	N
Students provided better interpretation and discussion of the results	N	N	A	N	N	N	A	A	N	A
Students asked more higher level (not technical) questions during the experiment	N	N	N	N	N	N	N	N	N	N
Other Observation: Students helping each other			Yes			Yes			Yes	

SA Strongly Agree A Agree N Neutral D Disagree SD Strongly Disagree

Instructor Observations of Interactions and Students' Behaviours (RQ4)

The semi-quantitative results of Table 2 derive from the instructor's observation of students' execution of the experimental work. The order of the session columns labelled from A to J is based upon increasing percentage of completion of the online preparation modules by students in the group undertaking the session.

The observations made by the instructor during laboratory sessions confirm, to some extent, the results in the previous sub-section from students' self-reporting. The instructor noted that, in only about half of the sessions, students could generally obtain accurate results more quickly than in previous years. Similarly, they did not perceive any significant improvement in the students' time management, ability to interpret and discuss the results, and level of reflection during the experiments. However, students appeared to ask fewer technical questions at the beginning of the sessions and were considerably more capable of identifying and correcting measurement errors on their own. These observations indicate that the introduction of the online preparation modules as additional material made some students better prepared for the experimental work, and that these students can potentially improve the quality of their group's overall execution of the technical tasks.

In most sessions, the instructor noted that students required fewer clarifications on the conduct of the experiments than in previous years (without the online preparation modules). More importantly, it was observed that students were significantly more autonomous in their work. Indeed, in 9 of the 10 sessions represented in Table 2, the instructor judged that students needed less support, could identify and correct measurement errors with less assistance, and/or discussed more the conduct of the experiment within their group. In addition, the instructor commented that students were helping each other more notably than usual in at least three sessions.

The semi-quantitative analysis reported in Table 2 also shows that there was no correlation between the changes observed in comparison to previous years and the composition of the groups in terms of general performance categories. By contrast, the increase in students' autonomy and group interactions was more likely to occur in sessions in which about two thirds of the students completed both modules prior to the laboratory. Therefore, the formation of groups with a range of levels of preparation appeared to be a significant factor contributing to the alteration of the group dynamics in the face-to-face laboratories. This evidence suggests that making the completion of the online modules voluntary can stimulate student-student interactions and contribute to changing the role of the instructor to a facilitator rather than as a dispenser of information (Wei, et al., 2018).

Discussion

From the foregoing results that specifically address each of the research questions posed we may adduce the impact of online-preparation modules on students' engagement and student interactions. These are described below, followed by a sub-section on the limitations of the present study that serve as a cautionary note on the more general validity of such findings.

Impact on Student Engagement

The following points may be inferred from the study:

- The high level of online preparation module take-up in advance of undertaking the actual laboratory indicates that students were planning their study and therefore suggests that they were engaged with their studies within the fluid-mechanics unit,
- As indicated by their satisfaction levels with the online-preparation modules, students were interested in the background and contextual material presented in the online modules, thereby further engaging them in the scientific/theoretical concepts of the unit that are illustrated through the laboratory work, and
- The fact that students reported that they continue to value the instruction sheet alongside the online-preparation modules (that were deliberately matched to specific aspects of the laboratory work) suggests increased engagement and familiarity with multi-media learning resources (Alexander & Lansbury, 2021); such experiences may serve to aid students in their further study and, later, continuous professional development as engineers.

Impact on Interactions

During laboratory learning, students typically engage in three main types of interaction (Wei, et al., 2019), namely those with the equipment, with other students and with the laboratory instructor. The present study highlights the following:

- ***Student-equipment interactions:*** Students felt competent and confident about using equipment and gathering data as reported by students and observed by the instructor.
- ***Student-student interactions:*** Students were confident working with each other as self-reported in addition to which the use of the online-preparation modules by some students appeared to increase peer-to-peer learning in the group activities (as reported by the instructor).
- ***Student-instructor interactions:*** While half of students reported the continued need for an instructor, the online modules reduced students' reliance on a detailed experimental demonstration at the start of the laboratory while the increased student-student interactions noted immediately above made the groups more independent of the instructor.

Limitations of the Study

The only instructor from whom observations were collected had to judge students' abilities and behaviours in comparison with those of previous years' cohorts from memory of their experience. While several instructors' assessments would provide a more comprehensive and balanced analysis, the single instructor survey ensured a high level of consistency in the comparison conducted between sessions.

The student survey data analysed in this study were gathered for one laboratory in a single year. Also, the cohort segmentation into groups based on academic achievement resulted in a comparatively lower number of students in the low-performing category. An investigation conducted over several years for multiple laboratories of different units would allow a better determination of statistical uncertainty and thereby draw more emphatic conclusions. However, considering the cross-disciplinary nature of the unit, the large number of survey participants (136), the high response rate (80%) and the representative performance distribution, the study sample group appears to characterise typical students enrolled in an Australian undergraduate engineering course, so that the findings reported in this study can be generalised and applied more widely.

The present study did not seek to determine whether the use of the online-preparation modules increased students' attainment of the laboratory learning outcomes as, for example, measured by marks awarded. Indeed, marks for this assessment are usually high and a quantitative analysis would have provided limited results. The effects of the modules on students' actual attainment of targeted laboratory learning outcomes are deferred to a future study.

Conclusions

Pre-laboratory online-preparation modules have been developed and deployed as an additional resource for students undertaking their assessed practical work, conducted in small groups of students, in a second-year engineering unit. A survey of students' opinions and experiences was conducted alongside semi-quantitative observations recorded by the laboratory instructor to determine the effects of the modules on students' engagement and their interactions. The following main findings emerge from the study.

1. Although voluntary, a significant proportion of the student cohort engaged with the modules and, overall, reported their satisfaction with this new resource. It was found that the most likely adopters of the modules were students with a mid-level of academic performance as compared with high- or low-achieving students.
2. It was found that students valued the online modules for the preparation it gave them in the technical aspects, i.e. operating the equipment and reading its instrumentation, and,

to a lesser extent, the broader introduction and background to the "real-world" context of the experimental work. However, students continued to value the traditional paper-based laboratory-instruction document used in tandem, especially for data-collection, data-processing, and the interpretation of results. Accordingly, it appears that the online-preparation modules serve not as a replacement but as valuable complement to the traditional laboratory-instruction document, especially in targeted aspects of laboratory work and communicating its relevance.

3. There is no evidence that use of the online preparation modules increased students' self-assurance in conducting the face-to-face laboratory. About half of the cohort, despite using the modules, reported that they continued to prefer a laboratory instructor to be present in their session. Thus, the modules do not serve as a replacement for the laboratory instructor. However, they appear to modify student-instructor interactions with the role of the instructor transitioning from being a director of the laboratory activity to one of guiding the students and facilitating their learning.
4. All students, whether or not they completed the online-preparation modules, were confident in their ability to interact with fellow students when carrying out the laboratory activities within a student group. Observations made by the laboratory instructor suggest that their interactions and overall student-autonomy were stronger than those seen in previous years' cohorts prior to the introduction of the modules. This may suggest that the modules did enable the student-cohort studied to take greater responsibility for their learning and be prepared to engage in an increased level of peer-to-peer learning.

The overall purpose of the study was to reveal how online preparation modules might enhance students' engagement with their study and promote both independent (from the instructor) learning and peer-to-peer learning via student-student interactions during laboratory work. In these regards, the present findings generally show that the modules achieved their design objective.

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