Integration of Interactive Laboratory Videos into Teaching Upper-Undergraduate Chemical Laboratory Techniques

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ABSTRACT

Students in advanced undergraduate chemistry laboratories are required to undertake a wide
10 range of complex and multi-step syntheses and analytical procedures, and prospective employers
of chemistry graduates seek students with proven skills in these areas. Our approach has been to
use video resources which are made available to students both ahead of, and during, their
laboratory classes to assist with preparation and provide just-in-time self-help during the
laboratory. In this study we evaluate the implementation of a user-focused strategy to improve
15 students' laboratory skills and use a three-stage model, forethought, performance and self-
reflection, to assess the impact and effectiveness of these resources to complement the traditional
laboratory teaching resources of laboratory manuals and laboratory teaching staff (demonstrators).
Students demonstrated autonomous learning by engaging with the laboratory videos using both
active and passive learning approaches. The benefits of our approach are especially evident for
20 students who have English as a second language and students who identify with different learning
preferences. Increased student grades and more effective staff-student supervision time
requirements are evident across both third-year undergraduate chemistry courses in which these
videos were implemented.

GRAPHICAL ABSTRACT

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KEYWORDS

30 Upper-Division Undergraduate, Laboratory Instruction, Analytical Chemistry, Organic Chemistry, Computer-based Learning, Laboratory Equipment/Apparatus.

INTRODUCTION

35 Employers in the STEM fields, including chemistry, are reported to have a duality between expected and desired skills along with higher expectations of formal instruction for technical skills, analytical/quantitative skills, communication skills and problem-solving skills.¹ Furthermore, employers place a high value on graduates' ability to apply skills and knowledge.² Many studies echo the importance of discipline specific knowledge and practical skills, along with teamwork, communication and problem-solving, to the preparedness of chemistry graduates for employment, research or further study.³⁻⁸ From the chemistry graduate perspective, those with a high level of chemistry in their work activities identified that their development deficits were with generic skills, and notably chemical instrumentation skills, analytical techniques and planning experiments.⁹ Similar, requirements are prioritized by employers of chemistry graduates, along with manipulative practical skills, and safe handling of chemical materials.¹⁰

45 Practical work is a principal component of the chemistry curriculum in a Chemistry Major within an undergraduate degree. Such programs of study are accredited by professional organizations, such as the Royal Society of Chemistry,¹¹ the Royal Australian Chemistry Institute¹² or the American Chemical Society.¹³ The accreditation requirements for chemistry courses at Bachelor level typically specify the need for a significant practical component. As part of the Royal Society of Chemistry accreditation of degree programmes,¹¹ there is a requirement for completion of at least 300 hours of assigned practical work, whereas the Royal Australian Chemistry Institute

guidelines¹² expects about one-third to one-half of the learning activities for a student to be in laboratory work. Furthermore, the Royal Australian Chemistry Institute believes that chemistry is
55 'fundamentally an experimental science for which achievement of excellence in practical skills is an essential requirement' and in order to acquire practical skills, students need to gain experience in laboratory work in adequately equipped laboratories.¹⁴ A common challenge with upper undergraduate chemistry is that chemical synthesis and analytical chemistry require more intensive laboratory experiences that require students to carry out appropriate safe techniques in
60 multiple settings, to correctly plan experimental activities and to develop skills and knowledge of equipment and instrumentation. This study reports on our evaluation of a strategy to improve students' proficiency with advanced chemical laboratory techniques and instrumentation.

LITERATURE BACKGROUND

65 The area of student experiences for chemistry laboratory preparation and non-human interactive instruction has been the topic of research that has produced several suggestions for teaching methodologies. Past research has indicated that pre-laboratory activities can assist with information overload associated with experiential learning during laboratories and improve the experience of students through pre-exposure to experiments and procedures.^{15,16} In addition to pre-
70 laboratory theory quizzes, pre-laboratory activities can include safety information, simulations, technique videos and expectation preparation for laboratory work. The range of pre-laboratory activities for university chemistry was recently reviewed.¹⁷ Emergence of pre-laboratory frameworks include a focus on "supportive information", which is the information related to underlying theory and rationale for experiment approaches and procedures¹⁷ and a framework for the development of
75 web-based multimedia pre-laboratory modules.¹⁸

Online sources for content provision in chemistry higher education are increasingly prevalent, as technological solutions are more available. Effective activities for students include online pre-laboratory preparation targeted to upcoming laboratory sessions,¹⁹ watching online videos of exemplary demonstration of laboratory skills in advance of laboratory sessions to increase student
80 confidence,²⁰ data analysis videos to alleviate the disconnections that can occur with delivery of rotation style labs²¹ and laboratory safety videos to facilitate student engagement with workplace health and safety along with assisting students to feel better prepared for laboratory sessions.^{22,23}

Reports on the use of instructional videos is rapidly growing. Approaches include student generated videos for laboratory experiments;^{24,25} the flipped classroom video method utilizing a GoPro camera to educate students on the background information on the experiments from a first-person instructor perspective;²⁶ the point of view laboratory demonstration using Google Glass²⁷ and immersive 360° panoramic videos, which had drawbacks associated with lack of focus and disorientation.²⁸ Aspects, in addition to those above, that emerged from these reports identified improvement of teaching consistency,^{26,27} that students required less teaching assistance during laboratory when they used pre-laboratory video instruction,²⁴ that pre-laboratory videos on 'Technique' were the most helpful for students during the laboratory,²⁵ and the potential of the instructor point of view videos for real-time distance learning.^{26,27} All reports were focused on the use of pre-laboratory videos.

Various studies on pre-laboratory and use of instructional videos have reported mixed results. In a study of second year analytical chemistry, students responded positively to pre-laboratory video instructions, but student performance was not improved.²⁹ The delivery of laboratory information for student laboratory teams was more effective when it was presented in an on-demand podcast format than a pre-laboratory lecture format.³⁰ Furthermore, the study identified that student interactions with teaching instructors during laboratories were significantly fewer for those who had accessed the pre-lab podcasts.³⁰ In a study of second year organic chemistry, supplemental videos to pre-laboratory preparation improved student efficiency in the laboratory and increased their procedural and content knowledge for the laboratory activities, as compared to students who did not view the pre-laboratory videos.³¹ Similarly, in a general chemistry laboratory, online pre-lecture videos had significant potential for improving student learning during a general chemistry laboratory and for reducing demand on institutional resources for associated courses.³² No change was observed to help-seeking behavior during laboratory sessions, perhaps due to the general chemistry level of study.³² Of interest is a related study of engineering students, in which a three stage model was created for student preparedness: The stages were termed the 'Realization Drop', where the preparedness drops over short times; the 'Active Gain', where the preparedness increases over time and was associated with spending time understanding what to do, watching the videos and reading the laboratory manual; and the 'Confidence Plateau', where more time spent preparing has very little effect on the preparedness level. The study concluded that videos used for

pre-laboratory preparation are successful, increasing not only the preparedness of the students but also the marks gained in their assessment.³³ Furthermore, it was identified successful pre-laboratory videos should be accessible, avoid being information dense and present key material in a short period of time.

Interactive instruction, such as interactive video-illustrated computer programs during upper level chemistry kinetics laboratory sessions, have been shown to increase the resulting laboratory skills of students and shorten the time of completion of the experiment by students.³⁴

Furthermore, the use of interactive instruction for kinetics was demonstrated to lower the number of erroneous or uncertain responses by students.³⁴ Similarly modeling and simulation approaches for teaching physical chemistry are known.³⁵ Literature for interactive video instruction typically describes chemistry that can be calculated on a computer and does not illustrate wet chemistry examples. The lack of studies which focus on interactive, in-lab videos to help students with wet chemistry laboratory preparation and instrumentation prompted the work described herein. Such approaches for interactive instruction could cover a wide range of hands-on advanced chemical and instrumental techniques during laboratory sessions, such as organic and analytical chemistry.

We propose a strategy to improve third year chemistry students' foundational skill and proficiency with advanced chemical laboratory techniques and instrumentation, which is adaptable, and user focused. The strategy is composed of multi-perspective filming of experimental activities that could be viewed by students *in-situ* during laboratory sessions on a mobile device (iPad), and augmented as a pre-laboratory activity. The same videos were used during the period of the study (2017-2019). Details of production (including creation and editing by instructors) of the videos for advanced chemical experimental techniques were recently reported.³⁶ We consider that the implementation of the *in-situ* interactive laboratory videos by integration into the laboratory sessions, described herein, could improve student autonomy during laboratory sessions and permit instructors to focus on higher level learning. Furthermore, it could offer students opportunity to develop their skills in advanced chemical instrumentation and techniques through active and self-regulated learning.

The Self-Regulated Learner Framework³⁷ was identified as appropriate for our study because it allowed us to monitor student use and experiences of the interactive laboratory videos during the

chemistry courses. There are three phases: the forethought phase, during which students activate existing knowledge and prepare for the task; the performance phase during which student
145 students perform the learning task and the reflection phase, during which student reflect on their approach toward the task. Self-regulated learning theory defines learning as a goal orientated process, that assumes learners learning goals steer their learning, with the learner making conscious choices when working towards their learning goals.³⁷⁻³⁹ There appears to be consensus about the three important phases of self-regulation: forethought, performance, and reflection.^{40,41}

150 The purpose of this study is to assess the effectiveness of the integration of the interactive laboratory videos and thus the following research questions were addressed:

- 1) To what extent did students engage with the videos during/prior to their laboratory sessions?
- 2) To what extent did interactive laboratory videos, assist development of chemical
155 practical knowledge and skills at the upper undergraduate chemistry level?
- 3) What were the observations about implementation of the lab-videos on student outcomes?

160 METHODOLOGY

The stages of the study were aligned with the three phases of the Self-Regulated Learner Framework³⁷ as follows: Students engage in the *forethought phase* by reading the laboratory manual procedures and viewing the videos on the learning management system (LMS). The videos provide support to students on the goal setting and learning goal orientation parts of the
165 forethought phase – Research Question 1. The *performance phase* includes interactive use of the laboratory videos on an iPad, or passive viewing of the laboratory videos on the TV screens, whilst carrying out the experiments, techniques or use of technical equipment during the laboratory session. Potentially, interactive, and passive videos provided support to students on self-instruction, attention focusing and task strategy parts of the performance phase. The same videos
170 were used for *forethought* and *performance phase* to facilitate comparison of mode of delivery and not introduce a content variable. A *self-reflection phase* was introduced during the study through student voluntary participation in student surveys. The survey questions provide students with an

opportunity for the self-evaluation and self-reaction aspects of the self-reflection phase. In our study, the students use, and experiences of the interactive laboratory videos will give us insights into the affordances and constraints using this supplemental type of instruction for laboratory learning in third year chemistry courses – Research Question 2. The reflections of teaching staff in these courses form the basis of our response to Research Question 3 combined with the open-ended question responses from students in the courses. Examples of all surveys are included in the Supporting Information.

Participants and setting

The study was conducted at a large multi-campus public research Queensland University as a pilot study in 2017 followed by implementation in 2018-2019 into two third year chemistry courses. The research participants of the study were comprised of students studying an Instrumental Chemical Techniques course and/or an Advanced Organic Chemistry course. The Instrumental Chemical Techniques course enrollment consisted of students completing degrees in Forensic Science and Biomolecular Science (Table 1). The Advanced Organic Chemistry course enrolment consisted of students, including a large cohort of international students with English as a second language, completing degrees in Science, Forensic Science or Biomolecular Science (Table 1). For the purposes of this study, at times the student group will be considered in three subgroups based on different timings of course offerings and student demographics in the larger course; where Instrumental Chemical Techniques is one sub-cohort and the Advanced Organic Chemistry course had two sub-cohorts: domestic students and international students who had non-English speaking background (NESB); in the context of this study where the language of instruction is English.

Table 1. Student Demographics for the Sample from Academic Years 2017–2019

Course	Year	Total Students by Year	Students' Residency Status		Students Pursuing a Degree in		
			Domestic	International	Science	Forensic Science	Biomolecular Science
Instrumental Chemical Techniques	2017	24	18	6	4	16	4
	2018	31	24	7	7	19	5
	2019	17	17	0	3	14	0
Advanced Organic Chemistry	2018	96	23	73	9	14	73
	2019	91	27	64	11	19	61

The Instrumental Chemical Techniques course was offered in intensive mode for two weeks in November, with contact learning activities of three keynote lectures and stand-alone laboratories of six hours (two 3-hour blocks) per day during two weeks in November from the contact teaching period in November-February (Trimester 3). The experiments within the laboratory sessions were taught on a rotational basis. The Advanced Organic Chemistry course was offered for 12 weeks from end of February to June (Trimester 1), with contact learning activities of lectures and tutorials divided into five themes and concurrent laboratories of four hours per week during the last six weeks of the teaching period, comprising of two multistep 3-week syntheses. The ratio of demonstrating staff (laboratory instructors/teachers) to students during each laboratory session was in the range of 1:10 to 1:12 for Advanced Organic Chemistry and in the range 1:5 to 1:8 for Instrumental Chemical Techniques. Occasional use of highly technical instrumentation, such as HPLC, ICP and GCMS was supported by technical staff for the Instrumental Chemical Techniques course. The laboratory videos were implemented during Trimester 3 2017-2019 (Instrumental Chemical Techniques) and Trimester 1 2018-2019 (Advanced Organic Chemistry). The individual assessment items and marking criteria for the laboratories in both courses remained the same for the reported years (2017-2019). Teaching staff were trained to apply the marking criteria consistently.

Implementation Details

The implementation of the videos created for Instrumental Chemical Techniques and Advanced Organic Chemistry are summarized in Table 2. The development and production of the videos as interactive resources for teaching chemical techniques during laboratory sessions has been reported elsewhere.³⁵ Consideration of the self-regulated framework led to integration into each course in multiple delivery modes; (i) Online mode in the LMS for the forethought phase where students could engage in forethought by viewing the videos through the LMS prior to laboratory sessions; (ii) iPad mode (videos installed as .mp4 files on iPad, to facilitate direct and immediate use) for the performance phase where students displayed active learning and interaction with the video during the process of carrying out the laboratory experiments, and (iii) Laboratory television screen mode, also for the performance phase, where students displayed passive learning by watching the videos from a distance at the time of carrying out the laboratory experiments. Lab

videos were typically of short duration and matched to the lab session on the laboratory television.

The smaller cohort in Instrumental Chemical Techniques enabled every student to have a dedicated iPad (2017-2019), thus there was no requirement for use of the TV screens for video display. Whereas the larger cohort in Advanced Organic Chemistry, both modes (lab iPads and TV screens) were used during lab sessions in 2018, however this was restricted to TV screen mode in 2019, due to the lack of availability of lab iPads for that teaching period.

Table 2. Summary of Videos and Mode of Delivery by Course and Year

Course	Chemical Technique Video	Video Length (min:s)	Experiment	Year	Mode of Delivery
Instrumental Chemical Techniques	Steam Distillation	2:12	Natural Product Isolation	2017–19	LMS; Lab iPad
	Drop Counter	2:22	Analytical Titration	2017–19	LMS; Lab iPad
	LabQuest Instrument	0:49	Analytical Titration	2017–19	LMS; Lab iPad
Advanced Organic Chemistry	Weighing on a Balance	1:59	Multistep Synthesis 1 & 2	2018–19	LMS & TV; Lab iPad ^a
	Cutting Sodium Metal	2:58	Multistep Synthesis 1	2018–19	LMS & TV; Lab iPad ^a
	Organic Distillation	2:10	Multistep Synthesis 1	2018–19	LMS & TV; Lab iPad ^a
	Claisen Reflux	4:59	Multistep Synthesis 1	2018–19	LMS & TV; Lab iPad ^a
	TLC	5:47	Multistep Synthesis 2	2018–19	LMS & TV; Lab iPad ^a
	Separating Funnel	2:45	Multistep Synthesis 2	2018–19	LMS & TV; Lab iPad ^a
	Rotary Evaporator	2:07	Multistep Synthesis 2	2018–19	LMS & TV; Lab iPad ^a

^aThe Lab iPad offering was only available in 2018.

Data Collection and Analysis

A combined quantitative and qualitative approach was used to address the research questions.

The advantages of this includes that we could employ a combination of student use and survey data to give a sense of student interaction with the videos observed in this case study. Student survey questions sought to examine student knowledge, experience, and confidence to undertake key procedures with the laboratory activities (Supplementary Information). Students ranked on a Likert scale of 1 to 5; where 1 represented a low knowledge, experience, or competence and 5 represented a high knowledge, experience, or confidence. In addition, students self-assessed their usage of the videos and there was an opportunity to provide qualitative comments. Students ranked against statements for usage which included sped-up video, paused video and viewed whole video. Students self-assessed their preparation time against time periods such as 1-30 minutes, or 1-2 hours.

For the pilot cohort in 2017, surveys were administered pre-laboratory and post-laboratory to the same student cohort to gauge the impact of the videos on the students' level of understanding and competence. For the pilot study and subsequently for the main study in Chemical Instrumental Techniques, the survey questions were restricted to techniques with videos and one technique without (Soxhlet). Only surveys with matching pre- and post-survey codes were used in data analysis. Subsequently a combined survey was used in the main study in 2018-2019, due to the larger session cohorts and administered at the end of the laboratory component of the course for 2018 and 2019. The later survey formed the *self-reflection phase* and concentrated on the students' use of the videos both pre-laboratory session as preparation, and during the lab, as just-in-time assistance to undertaking the procedures. The schedule of surveys, survey sample size (*N*) and response rates (where course enrolments are listed in Table 1) are shown in Table 3.

Table 3. Study Timeline of Student Survey Points at Completion of Lab Component of Course

Course	Trimester	Administrations of the Student Surveys							
		2017 Pre-Survey ^a		2017 Post-Survey ^a		2018 Survey		2019 Survey	
		<i>N</i>	Response, %	<i>N</i>	Response, %	<i>N</i>	Response, %	<i>N</i>	Response, %
Instrumental Chemical Techniques	3	12	50	12	50	30	97	15	88
Advanced Organic Chemistry	1	—	—	—	—	84	87	61	67

^aThis was the pilot cohort.

A brief post-laboratory survey for demonstrating staff, administered at the same time as the student surveys, gave some data regarding assistance provided to students for individual experimental techniques during the laboratory sessions in both courses along with brief qualitative feedback. Due to the complexity of labs not all staff taught every technique, resulting in response rates to the individual survey questions in the range 33-100%. Staff Surveys were collected for demonstrators in Instrumental Chemical Techniques (2017-2019; 25 laboratory sessions) and Advanced Organic Chemistry (2018-2019; 72 laboratory sessions) (Supplementary Information). For analysis, responses to the staff surveys were aggregated by total demonstrating staff and individual laboratory session size for both courses: Advanced Organic Chemistry course

(demonstrating staff, n=3; students per laboratory class, n=10-30) and Instrumental Chemical
Techniques course (demonstrating staff 2017-2018, n = 3; students per laboratory session 2017-
2019, n=11-30).

Data regarding the usage of videos on the LMS outside of the laboratory session was obtained
from self-reporting through the student survey. This ensured mapping of the users undertaking
the laboratory sessions because the LMS hits were aggregated and included other users (academic
staff, educational designers). It is noted that there is a degree of uncertainty with self-reporting
data. Analysis of quantitative data from all cohort surveys for each question and laboratory marks
were carried out in Microsoft Excel.

Ethics approval was obtained in line with the institutional guidelines. Students and staff were
informed about the research prior to voluntary completion of a survey and were offered the right to
withdraw their contribution. No incentives were given to the students to use the iPads or view the
videos online or on the laboratory TV screens.

RESULTS AND DISCUSSION

Pilot Study

The questionnaire designed for the pilot study determined (i) how much time students spent
preparing for their laboratory sessions and (ii) student knowledge of, and confidence in,
undertaking three analytical processes; self-assessed both before and after they undertook the
laboratory sessions. Pre-laboratory activities were categorized as online (self-directed online
activities, not set by the course tutor), watching videos and other activities (reading the manual,
practicing calculations etc.). Most students (>50%) spent 1-30 minutes on online activities and
watching the videos and the same majority spent 31-60 minutes on the other activities.

Responses to the questions determining knowledge of, and confidence in setting up, and ability
to perform, the techniques before and after the labs were conducted were aggregated into three
categories: high (very high/high), average, and low (low/very low) (Figure 1). Student knowledge of,
and confidence in setting-up and ability to perform each technique before the laboratory sessions
were low (>70% of respondents) and this was expected as students were inexperienced at these
techniques at the time of the survey. For the techniques which had accompanying videos (drop

counter; steam distillation), the students' post-laboratory confidence (for setting up and ability to perform) had increased markedly with more than 75% of respondents stating they had high knowledge of and confidence in the techniques, with a further 10-25% stating their response as average. In contrast, the Soxhlet extraction experiment, which did not have an associated video, saw students reporting that their knowledge of, and confidence in this experiment after the laboratory was completed was far lower; with 40% of respondents still scoring low or average to this question (Figure 1).

Figure 1. Student knowledge of, confidence in setting up, and ability to perform the experimental technique pre- and post-laboratory session – Pilot Study (2017). Techniques without videos (Soxhlet) and with videos (Drop Counter and Steam Distillation).

Main Study – Preparation/Forethought Phase

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Research Question 1: To what extent did students engage with the videos prior to their laboratory sessions?

Main study: pre-laboratory activities

330 Students were asked to state how much time they spent preparing for laboratory sessions across four categories; online activities, watching other relevant videos (e.g., YouTube), reading the laboratory manual and doing practice calculations, and specifically watching the laboratory videos posted on the LMS course sites. All pre-laboratory activities were optional for students and not part of a formal pre-laboratory activity.

335 The amounts of time spent on each activity showed considerable variation (Figure 2). Across both years, over half of the Instrumental Chemical Techniques students spent 1-30 minutes watching the laboratory videos on the course site as preparation for the laboratories whereas very few (less than 10%) spent more than 30 minutes viewing the same videos. In comparison, while over 50% of students in Advanced Organic chemistry also spent 1-30 minutes viewing laboratory videos on the LMS, another 23% of students spent more than 30 minutes viewing the same videos.

340 The preparation activity that took students most time, in both courses and across both years, was the 'other activities' – reading the laboratory manual and practicing calculations – with approximately 40% of students spending over 31 minutes on this activity in addition to approximately 50% who spent 1-30 minutes on this activity.

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Figure 2. Student preparation for laboratory (Time and Activity) for Instrumental Chemical Techniques and Advanced Organic Chemistry – Main Study (2018-2019).

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The students were surveyed on what extent they agreed that each resource was useful to them. The responses indicated that the number of students watching the videos before the laboratory class were consistent across both courses and both years with between 77% and 86% of students agreeing or strongly agreeing that the videos were a useful pre-laboratory resource (Table 4).

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Table 4. Student Perceptions of the Usefulness of Watching Laboratory Videos before a Laboratory Session

Course	Year	Respondents by Course and Year, <i>N</i>	Students Selecting These Rating Categories, ^a %				
			Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Instrumental Chemical Techniques	2018	30	0	0	23	40	37
	2019	15	0	0	16	37	47
Advanced Organic Chemistry	2018	84	0	0	14	38	48
	2019	61	0	2	13	60	25

^aResponses to a survey item asking students to indicate to what extent they agreed that the video resource was useful to them during prelab preparation.

360 **Main Study – Undertaking/Performance Phase**

Research Question 2: To what extent did students engage with the videos during their laboratory sessions?

During the undertaking phase the survey responses (n = 190 respondents) established which
365 resources were useful to students during laboratory sessions. Students (98-100%) agreed or
strongly agreed that laboratory demonstrators were a very useful resource within the laboratory
and over 90% of students also agreed or strongly agreed that the laboratory manual was a useful
resource. Although there was a minority of students (13%) that were undecided, 86% of students
agreed or strongly agreed that the laboratory videos were a useful resource during the laboratory
370 (Figure 3). Inclusion of the laboratory videos during laboratory sessions were a clear complement to
existing resources and were not ignored or poorly valued for usability.

Figure 3. Usefulness of resources for Chemical Instrumental Techniques (n =45) and Advanced Organic Chemistry (n =145)

The viewing figures for students watching the videos during the laboratory sessions are consistent across both courses in 2018 with between 84% and 89% of students agreeing or strongly agreeing they were a useful resource. In 2019 however the videos were only available on iPads in Instrumental Chemical Techniques (where 87% of students found them a useful resource) whereas in Advanced Organic Chemistry they were only on the television screens in the laboratory due to a lack of availability of iPads for that teaching period (Trimester 1, 2019). In this instance only 77% of students agreed or strongly agreed that they were a useful resource. This variance (7-12%) hinted towards a potential identifiable difference in students use of passive resources (watching on TV screens in lab) versus active resources (interactive video on iPads).

The data from both Instrumental Chemical Techniques and Advanced Organic Chemistry in 2018 and 2019 are given in Figures 4 and 5. Viewing activity was recorded by students on their surveys and was then classified as either active viewing or passive viewing. Active viewing included

pausing, speeding up or slowing down the video or repeating sections whereas passive viewing was simply watching the whole video on the device or on a TV screen. The instrumental Chemical Techniques students indicated higher active and both active/passive views of the videos (58-73%) during laboratory sessions of (Figure 4). By comparison Advanced Organic Chemistry students with displayed views of 39-46% for active and both active/passive views of the videos (Figure 5), which may be due availability of the videos on the laboratory TV in addition to the iPads (in 2018) and the strong agreement that demonstrators were helpful (Figure 3). Active views during a laboratory may indicate students used the videos in a targeted way, perhaps reflective of pre-laboratory preparation and student reluctance to publicly ask questions. Passive views during a laboratory may indicate students were seeking understanding of the complete technique, or for the larger class, that the iPads were in use by other students at the time the student intended to view the video.

Figure 4. Viewing activity level of the Laboratory Videos – Instrumental Chemical Techniques

Figure 5. Viewing activity level of the Laboratory Videos during laboratory sessions – Advanced Organic Chemistry

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The staff survey provided an indication of the level of assistance given by staff to students during the laboratory sessions. Responses were ranked for each laboratory technique with and without a video. Minimal assistance (57-100%; able to carry out technique without asking help from a demonstrator or other student) was required for all techniques that have an associated video, apart from steam distillation where students required some assistance (49%; asked one question that required an explanation or asked for brief reassurance or brief help from the demonstrator or other students). In contrast, for Instrumental Chemical Techniques, students required some to extensive assistance (89-91%; asked two or more questions that required an explanation or asked for reassurance or help from the demonstrator or other students) for techniques without a video (Soxhlet Extraction, Table 5). Assisting students with this experiment was a significant part of the demonstrators' role in this course, with students requiring considerably more assistance to set-up and run the Soxhlet experiment compared with the other two experiments described in this study, where lab videos were provided to students.

Table 5. Comparison of Assistance Levels Given to Students during Laboratory Sessions, by Technique

Course and Technique	Students per Session, <i>N</i>	Availability of Video for Technique	Distribution of Assistance Level for All Sessions, %		
			Minimal Assistance	Some Assistance	Extensive Assistance
Advanced Organic Chemistry: 36 Laboratory Sessions					
Weighing on a Balance	15–22	Yes	100	0	0

Cutting Sodium Metal	15–22	Yes	60	40	0
Claisen Reflux	15–22	Yes	57	33	10
TLC	15–22	Yes	70	20	10
Separating Funnel	15–22	Yes	75	25	0
Rotary Evaporator	15–22	Yes	70	30	0

Instrumental Chemical Techniques: 18 Laboratory Sessions

Steam Distillation	24–31	Yes	42	49	9
Drop Counter	24–31	Yes	67	33	0
LabQuest Instrument	24–31	Yes	67	33	0
Soxhelt Extraction	24–31	No	11	29	60
Markham Still	24–31	No	9	87	4

Main Study - Reflection Phase

Research Question 3: What were the observations about implementation of the lab-videos on student practice?

The videos clearly worked best for students when they were viewable on a portable electronic device which students could control. In these circumstances most students found they improved both the knowledge of the technique and their confidence in undertaking the experiments. This observation was corroborated by the views of the demonstrators who stated that the use of videos reduced the number of students who needed significant assistance with techniques. In addition, students were more autonomous in these laboratories compared with other sessions and demonstrators could concentrate on the laboratory, as well as explaining individual experimental set-up to students. Demonstrators also commented that students seemed to really engage with the videos especially for help with setting up the apparatus. However, not all laboratory technical staff were positive in their responses. One raised a concern about the fume hoods being overcrowded with equipment since the addition of an iPad into the experimental set-up.

It was interesting to note that the laboratory marks for experiments using procedures with associated laboratory videos were improved from 65.8% (SD 16.5) prior to the implementation of videos on iPads to 87.6 % (SD 13.1) when the laboratory videos were used during the Advanced Organic Chemistry laboratory, and this was associated with a large Cohen's d value⁴² of 1.43. Further analysis within this change revealed that the NESB student laboratory marks were the

greater contributors irrespective of the year cohort or experiment. This observation was associated with large Cohen's d value of 1.12 to 2.05 for the NESB students (2018-2019), as compared to a negligible or small change for the laboratory marks attributed to the domestic student sub-cohort (2018-2019; Cohen's d values of 0.02 to 0.7). In contrast, sub-samples ($n = 0$ in 2017) were too small for statistical analysis, thus an observation was made that the laboratory marks for experiments Chemical Instrumental Techniques were not directly impacted. This may be due to the low (0-25%, Table 1) of NESB students in this cohort. Instead, staff gave feedback on observations during laboratory sessions that the videos on iPads '*assisted some students*' and '*students used with interest*'.

Reflection - Staff Comments

Staff gave other feedback on observations during laboratory sessions including they '*liked the annotations*' and that the '*labels of equipment were good for student understanding in the videos*'. Students that were known to be slow, poorer at laboratory skills or demonstrated poor confidence, '*still asked for help after using iPad*'. It was noted that in the course with the larger NESB cohort '*some students watched big screen in preference to iPad*.' Workplace health and safety considerations from staff included concerns about the '*constrained space in fume hoods*' and the '*potential to drop the iPads*'. This could be resolved by stands (fixed or flexible; lab bar stool seats) located next to a fume hood for iPad placement. The potential to drop any equipment is not limited to iPads. A positively changed approach to demonstrating was revealed by comments such as: '*As a demonstrator I could concentrate on the lab as a whole rather than explaining experimental set-up to individual students*' and that the approach '*allowed student to self-select use of iPad for extra instruction*'.

Reflection - Student Comments

Students' statements (52 comments in 2018-2019) identified the usefulness of the laboratory videos during laboratory sessions in several themes. The videos were found to assist with self-management of set-up of experimental equipment as the Instrumental Chemical Technique cohort

commented that they *'allowed students to try new techniques/setting up equipment themselves'* and *'allow[ed] students to work independently'*. It was recognized by these students that the videos
485 *'definitely help in the lab if you become stuck or the manual is unclear'*. Some of these students acknowledged the integrated approach to technical support as it meant they *'could watch and pause the video while doing the lab'*. Notably this approach appealed to students with different learning preferences; *'as a visual learner, seeing how experiments/techniques are carried out helps me to retain information better'* and *'it was good to see a video rather than reading it on paper. It*
490 *made things more clear.'* The videos provided an effective augmentation to laboratory demonstration, with Advanced Organic Chemistry students making other comments such as *'the lab videos were extremely effective in displaying how lab practices should occur'*, *'very helpful for providing information during lab sessions'* and *'the video slowly and clearly demonstrated the process'*, along with recognition of the impact of student-demonstrator interactions: *'were a big*
495 *help if ever got stuck and a demonstrator was not available (due to helping other students)'*. Suggested improvements, potentially from the NESB student cohort, included *'add more details of steps'* and *'be short because we do not have too much time'*. The later comment was surprising given the videos were between 0.49 – 5.47 mins in length.

500 Limitations

The study focuses on participants that were in their third year of studying undergraduate chemistry (having completed 4 semester of study) and had prior experience in chemistry experiments . A detailed statistical analysis of the pilot study questionnaire data was not carried
505 out due to the low sample size (n=12). In addition, the observation limit of 5 per category/variable used by typical statistical software (like SPSS) was not met in places. The aggregated collection of student data prevented statistical analysis for individual student outcomes. Other potential limitations of the study were the surveys were optional for students and the introduction of active learning is likely to be more enjoyable than didactic laboratory teaching for students.⁴³ Variables
510 such as individual student motivation levels, student's study load during a semester of study and degree of uncertainty with time-on-task self-reporting are unknown and cannot be controlled or reported.

CONCLUSIONS AND IMPLICATIONS

515 Integration of interactive laboratory videos into chemistry laboratory teaching has been shown to be an effective strategy to improve third year chemistry students' skill and proficiency with advanced chemical laboratory techniques and instrumentation. The strategy was composed of multi-perspective videos of experimental activities that could be viewed by students *in-situ* during
520 laboratory sessions on a mobile device (iPad) or laboratory TV and augment pre-laboratory activities through the LMS. The pilot study indicated apparent improvement in student knowledge and confidence in setting up and ability to perform techniques that have associated laboratory videos. Subsequently, the main study was aligned with the forethought, performance, and reflection phases of the Self-Regulated Learner Framework.³⁷

525 Prior to the laboratory sessions, student's preparation included reading the laboratory manuals, doing calculations, using online resources as well as watching the laboratory videos. Although an addition to traditional preparation activities, students spent typically up to 30 minutes watching the laboratory videos and identified them as useful pre-laboratory resources. Inclusion of the videos for use during laboratory sessions was a strong complement to existing
530 resources (demonstrators and laboratory manuals). Students actively sought interactive learning and used the iPads during laboratory sessions for just-in-time assistance, pausing, rewinding, and reviewing key sections whilst carrying out the experiments and techniques during the laboratory session. Other students were observed to engage with the videos in a passive way during laboratories by watching on the laboratory TV screens. Student's feedback from all sub-cohorts
535 was overwhelmingly positive, apart from extra comments from the international sub-group relating to requesting more detail in the videos. Use of the same videos during the period of the study (2017-2019) did not impact the study results, however we recommend alignment of the review cycles for course laboratory curriculum and the lab videos (including updates and edits).

540 Implementation of the *in-situ* interactive laboratory videos by integration into the laboratory sessions, described herein, improved student autonomy during laboratory sessions and permitted demonstrators to focus on the whole laboratory class and potentially on higher level learning with students. Use of videos on a mobile device *in-situ* during laboratory sessions could provide an

alternative for demonstrators and instructors for the provision of extra assistance for students. Students demonstrated self-regulated learning and development of their skills in advanced chemical instrumentation and techniques through use of the videos. The integration of interactive laboratory videos into chemistry laboratory teaching approach, presented herein, improved the students' outcomes for both courses and all sub-cohorts, especially in terms of the learning experience. Furthermore, for the sub-cohort of international (NESB) students, there were improvements in assessment marks. The videos are potentially appropriate for ab initio teaching of such chemical techniques, but in this study the videos are clearly identified as an effective augmentation to existing traditional approaches of laboratory manuals and demonstrators. The results suggest that even with low initial confidence, the approach assists student learning. The integrated videos reinforce technical skills acquisition for the chemical techniques and instrumentation specified and demonstrated to students how the techniques that they learned could help them develop their knowledge. The opportunity to watch an experiment being setup and performed is especially important to demonstrate the dynamics of chemical techniques to learners who are potentially disadvantaged if the instructions are solely in printed form. An unexpected advantage of this approach was that the videos supported development of an 'online laboratory experience' during the COVID-19 crisis through 2020. Student use of iPads *in-situ* potentially could facilitate ongoing physical distancing requirements in 2021 for the delivery of in-person labs. The application of this approach to assist experiential learning in other sciences should be explored. The approach reported herein is a flexible addition to chemistry teaching across a range of experimental techniques that is adaptable, and user focused and thus of general interest to chemistry and tertiary science educators.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX. [ACS will fill this in.]

Details of (i) Pre-Laboratory and Post Laboratory Survey for Instrumental Chemical Techniques
2017 Pilot, (ii) Student survey – Instrumental Chemical Techniques and Advanced Organic
Chemistry 2018-2019 (iii) Survey Laboratory Demonstrating Staff Instrumental Chemical
575 Techniques and Advanced Organic Chemistry, (PDF)

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Notes

There are no conflicts to declare by the authors.

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