Creating a Confident and Curious Cohort: The Effect of Video-Led Instructions on Teaching First-Year Chemical Engineering Labs

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ABSTRACT

10 On-demand video has become a seamless part of the fabric of information consumption. Initially inspired by the popularity of video guides for practical skills such as cooking and DIY, instructional videos were developed for equipment used in the first-year chemical engineering undergraduate teaching laboratory at Imperial College London. During 2016/17, the effect of the videos on the students' learning was measured using video viewership metrics, a survey and focus groups with students and Graduate
15 Teaching Assistants (GTAs) and rounded off through interviews with the module teaching team. Student reactions were overall positive, with >90% of students stating they found the videos useful. The outcome of our study indicated that because of access to the videos before, during and after lab sessions, students were more confident in their own ability, spent more time engaging with theory, applied practical lab skills in a more targeted way and produced better outputs. Rather than just a video version of the
20 experiment handout, the video influenced the behaviour of both learners and teachers, freeing up time to engage in deeper exploration of topics. The results of the study suggest that the use of video-led instruction in undergraduate laboratory teaching improves student experience, saves GTA time, and decidedly shifts the teaching focus from demonstration to exploration.

GRAPHICAL ABSTRACT

KEYWORDS

First-Year Undergraduate, Laboratory Instruction, Hands-On Learning / Manipulatives, Multimedia-Based Learning, Chemical Engineering, Physical Chemistry, Internet / Web-Based Learning, Problem Solving / Decision Making

INTRODUCTION

Widely adopted in education, the experiential learning theory (ELT) states that “learning is a holistic process of adaptation to the world... thinking, feeling, perceiving, and behaving”.^{1,2} This serves as the theoretical foundation for the laboratory learning modules in chemical engineering education,^{3,4} where students gain first-hand experience with data collection and analysis through the use of specialised equipment and tools. The ubiquitous use of computers and the internet has enabled educators to enhance experiential learning with e-learning materials such as digital notes and videos. By sharing such resources online, educators in the USA have started a revolution with the concept of massive open online courses (MOOCs), which enables learners around the world to learn from the best scholars in the field.^{5,6} Some educators have advanced e-learning further with the development of remotely controlled and virtual laboratories, which aim to deliver experiential learning to long distance learners.^{7,8} These modules have been successful in delivering conceptual knowledge^{9,10}, but it has been shown repeatedly that learners still prefer hands-on laboratory modules over distance learning.^{11,12,13} This preference implies that hands-on laboratory modules are still the most effective in delivering experiential learning

45 as it allows learners to appreciate the real-life context of the experiment (e.g. equipment limitations),
which is an important aspect of learning not quantifiable by report writing or examination. Although
hands-on laboratory modules have clear benefits for learners, educators are often deterred by the
resource intensive nature of such modules. As shown in previous case studies,^{3,14} the development and
delivery of hands-on laboratory modules require human time and expertise, equipment and
50 consumables. Strategies that reduce the requirement of any input while ensuring learning quality will
lower the barrier of adoption for educators.¹⁵

This paper reports a strategy that has been implemented in the Undergraduate (UG) Teaching Labs of
the Chemical Engineering Department at Imperial College London, UK, for reducing the human input
55 during the delivery of a hands-on laboratory module while enhancing learning. At the core of this
strategy are instructional videos that students have to watch before conducting experiments.^{16,17} These
videos reduce the training time that teaching assistants have to spend on each group of students and
promote the quality of intellectual engagement. Students come to the labs prepared to engage with the
theoretical concepts and context of the experiments, rather than focusing on just the practical aspects
60 of manipulating machinery. The authors of this paper aim to share best practice that is based on our
own and students' observations, so that interested educators can readily implement it in their own
settings.

PREPARATION AND DELIVERY OF INSTRUCTIONAL VIDEOS

Key problem and our approach

65 The chemical engineering programme at Imperial College London attracts a diverse and international
student cohort drawn from across the globe, with more than half being non-native English speakers.
First year chemical engineering students perform seven experiments during the teaching laboratory
module, Foundation Labs, held in the Spring Term. For each experiment students are provided with a
70 detailed experimental hand-out. Students are required to read hand-outs and prepare risk assessments
of their experiment before they report to the labs. Students are also expected to conceptualize an
experimental plan to effectively use their lab time. They have three hours to perform each experiment

and 15 days to analyse the data and write a report. During a laboratory session, each experiment is led by a dedicated Graduate Teaching Assistant (GTA), who explains operation of the equipment and assists students with any issue they encounter. Students readily understand the concept of the experiment, however, they often struggle with visualising equipment operation and compiling an effective workplan. Across the teaching team, it was found that a lot of GTA time within the lab was focused on resolving operational issues as students required constant assistance in equipment operation and data collection.

The effectiveness of video led instructions is well established in the literature^{18, 19}, and indeed many of us use videos on social media platforms and streaming channels to e.g. perform DIY tasks. These videos range from simple problem solving to constructing something from scratch and make a major contribution to developing motor skills²⁰. In the Summer of 2016, the undergraduate labs teaching team decided to apply this concept in the context of first year teaching with detailed, step-by-step equipment operation guides, an example of which is included in the supporting information. Students were expected to watch these videos before the corresponding practical session to understand how the equipment operates, what they can do with the experiment and what the various safety concerns are. In addition to this enhanced preparedness, students could refer to these videos during a lab session as well to promote a more effective time utilization.

Production of Instructional Videos

Videos were produced using the Panopto software, which is primarily used at the College for recording lectures in lecture theatres with fixed camera installations. Each experiment in the UG teaching labs is either benchtop mounted or located within a fume-hood and, therefore, would have to be filmed in place. Hence, the team constructed a video filming table with two fully flexible and adjustable arms on which individual webcams were mounted to capture both the equipment and the presenter simultaneously.

Table 1. List of Foundation Lab Instructional Videos

<i>Experiment Name</i>	<i>Video</i>	<i>Recorded by</i>
Conduction & Diffusion	1	LT
Flow Lines	2	LT
Bernoulli's Principle	3a	GTA
	3b	GTA
Solution and Reactions	4	GTA
Critical Point	5	LT
Viscosity	6a	GTA
	6b	GTA
	6c	GTA
Complexometric Titration	7	LT

Initially, the videos were recorded by an experienced lab technician (LT) with in-depth operational knowledge of all the Foundation Lab experiments. Once a framework for a consistent style had been developed, GTAs were also recruited for filming (see **Table 1**).

Delivery of Instructional Videos

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Although all necessary videos had been prepared by the start of term, they were not all made available immediately on the College's VLE platform as our study aimed to establish effectiveness of videos as a learning resource in comparison with traditional means. In order to establish a baseline control group, students were not provided any videos for the first two experiments, which were operated as traditional lab sessions with only written handouts for preparation. From the third project onwards, additional videos, which the students were required to watch, were introduced. During lab sessions, GTAs probed if the students had watched these videos and observed any difference in student preparedness and engagement.

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ASSESSMENT OF THE PEDAGOGICAL IMPACT OF INSTRUCTIONAL VIDEOS

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Collection of Video Metrics

Metrics on the watching of instructional videos by the student cohort were collected to ascertain the uptake of the videos as a resource. Data was collected from Panopto on the number of times videos were accessed, along with the total cumulative minutes watched for each video. Panopto also recorded the frequency and cumulative minutes individual students accessed individual videos, as well as the corresponding dates.

Collecting Stakeholder Views

As detailed in the earlier section, this study is designed to draw comparisons between the control group and the intervention within the same cohort of students, GTAs, and teachers. The effectiveness of the approach was evaluated using multiple methods such as anonymous surveys, focused group discussions, and in-depth stakeholder interviews during or at the end of the intervention.

Student views were canvassed using an online service, Mentimeter, which allows for anonymous and real time voting and collection of comments. Quantitative data needed be collected while students were using these videos, but the survey had to be simple and quick to do so that students would willingly engage with it. The students were asked three questions:

- Do you find the instructional videos for Foundation Lab useful?
- Do the instructional videos improve your teaching/learning experience for the Foundation Lab?
- Would you recommend using instructional videos to demonstrate experiments in the future?

Students could enter free text comments to qualify their answers and indicate how the use of videos could be improved.

To obtain more granular information about different aspects of the video delivery process and its effectiveness, a focus group interview involving all stakeholders was conducted by a team of researchers not directly involved with the project. Students and GTAs were invited to take part on a voluntary basis. A structured focus group session (17th March 2017) was organised immediately after the intervention and moderated with a specific set of questions, which are included in the supporting information. Insights from GTAs, as the primary point of contact with the students in the labs with first-hand experience in both teaching and creating the videos, were also collected then. To evaluate longer term effectiveness, a subsequent focus group with Foundation Lab GTAs was held in the academic year

2019/20 (27th March 2020). The module leader and teaching lab technician were not included to avoid potential bias due to possible power dynamics, and interviewed separately (5th April 2019 and 18th July 2019, respectively). All focus groups and interviews were conducted by researchers not involved with the initial intervention. Questions for the focus groups were written in advance and can be found in the supporting information. These were used as a guide for open ended conversations which were recorded and then transcribed. Analysis of the focus group data was carried out according to the principles set out by Sıdıka Gizir²¹. The same data analysis methodology was used for the interviews. Representative quotes from the discussions were selected by the authors based on relevance.

RESULTS & DISCUSSION

Student Perception

Statistics on the video viewership was recorded by Panopto. The data can be broken down per video, showing the time and timestamp for individual viewers and is shown in **Table 2**.

The number of unique viewers for each video varies from 64 to 87 students. The year group cohort consisted of 140 students, indicating that not all the students watched every video. As the videos were only available for the last five experiments, each video would have been relevant for 5/7^{ths} of the students i.e. 100 students. Therefore, the percentage of viewers from the expected number of viewers is approximately 60-90%. It is important to highlight that students work in groups of two or three and it is not mandatory for all of them to have watched instructional videos as long as the group is covered. Students sub-divide different tasks within their team, and watching videos is no exception.

Table 2. Data on instructional videos viewing

Video	Video Length	Number of Views	Sum of Minutes Viewed	Number of Viewers	Average Viewer Time
1	19m 20s	120	1128.35	70	10m 56s
2	13m 19s	115	768.09	74	7m 53s
3a	4m 16s	130	371.41	83	3m 17s
3b	1m 08s	87	74.57	64	56s

4	4m 08s	154	358.81	87	3m 06s
5	9m 37s	153	717.65	84	6m 29s
6a	2m 45s	95	199.02	69	2m 29s
6b	1m 45s	82	127.09	64	1m 41s
6c	1m 46s	83	124.29	65	1m 43s
7	12m 34s	107	672.47	77	6m 55s

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The number of views for each video exceeds the number of viewers, meaning that some users watched some of the videos more than once, though the modal average number of views for each was one. This is reflected in the student response during the focus group where it was stated that, “some students revisited the video(s) after the labs”. This access to the resource post-experiment is useful to some students to reaffirm the acquired knowledge during the write-up process. **Figure 1** shows there is a positive correlation between the mean number of views for each video and video length. Longer videos are re-watched more often than shorter ones, possibly as the longer videos represent more difficult experimental procedures.

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Figure 1. Chart showing the relationship between average number of views and video length.

The videos varied in length, with the videos filmed by the lab technician (LT) being significantly longer (mean average = 13m 43s) than those filmed by the GTAs (2m 38). This can be partially explained by the fact that five of the six videos filmed by the GTAs were split into themed parts, whereas the LT filmed videos of the whole experiment. Feedback from the student focus group stated that “some of the videos were too long” with seven to eight minutes being given for the optimum length. The average individual viewer time was shorter than the video length and significantly so for longer videos. There is a negative correlation between the length of the videos and the percentage of the video watched (**Figure 2**). This could be a consequence of some viewers watching multiple times (see **Table 2**), with some subsequent views being shorter in length than the whole video.

Figure 2. The relationship between percentage of video viewed and video length.

Anonymous polling of the students via Mentimeter found the respondents viewed the use of video on-demand positively (See **Figure 3**). Over 90% of respondents found them useful and would recommend

use in future. While the majority of respondents stated that the instructional videos improved their learning (79%), this is lower than the percentage that would recommend the use of videos in the future, and some comments revealed a caveat:

200 “The instructional videos are useful to help for the preparation to the lab; however they should not replace the instructions given by the GTA”

This student found instructional videos useful according to their Mentimeter vote, and their statement, but only for pre-laboratory instruction, rather than as a replacement for any current systems in place (GTA instruction and handouts). This fits in well with how pedagogic use of the videos was introduced
205 to students. Another respondent said:

 “The videos should match the handouts because sometimes they contradict each other”

In spite of not finding that the videos improved their learning experience, this student would still recommend using videos in the future. Several respondents indicated that the videos should contain more information and expand beyond the scope of the handouts in some cases:

210 “Perhaps give more hints and tips that aren’t on [sic] the handouts.”

 “The video[s] can be longer and gives [sic] a more specific explanation of the experiment.”

 “The videos are already very good, however to improve [them] one could provide more info on parts that students find tough during the lab times.”

 “More in-depth description of equipment.”

215 The results of the live Mentimeter polling (figure 3) were discussed in the focus group. In response to the question “Most students say the videos are useful, share why? (I.e. was it easier to learn, prepare them more, nice watching in advance)” the students concluded that the videos helped them “gain confidence before attending the labs”, arriving “better prepared”, and with a “clearer idea” of what the experimental equipment looked like and the experimental task. The focus group also revealed that the
220 videos helped with “breaking down the details contained with the hand-outs and visualisation of the equipment prior to the lab”.

These responses, along with the comments from polling confirm that the videos act as supplementary material to the handouts and contributed positively to the student experience. The students were adamant that the videos should not supersede the role of the GTA yet were very clear that “watching the
225 videos saved time”, and helped them use their lab time more effectively. Person to person interaction

still offers a significant element of reassurance, which is something the students do not want to miss out on.

Figure 3. Mentimeter polling of Students' opinions on the implementation of video led instruction in the Foundation Labs.

To complement the videos, they recommended that GTAs should summarise the video content, focusing on troubleshooting, rather than introduction/demonstration of the equipment as this would “bring more time and value to the discussion”. Overall, students acknowledged that the teaching approach of the GTAs was profoundly changed:

“Rather than giving a straight answer and spoon-feeding students, GTAs could offer more supervision, creating [a] more [...] engaging environment”, which “let them learn from their own mistakes” and helped them to develop a “higher level of confidence and eventually become more independent in the lab.”

Course Coordinator Perception

Individual interviews were carried out with the module leader and the lab technician. The impact of the videos was discussed from a technical and pedagogical point of view.

As stated earlier, video production was initially carried out by the lab technician who was familiar with all the experiments before the GTAs joined in later. Initially the LT found the process of filming the videos “difficult and nerve wracking” but after producing two videos he stated that he found “being in front of the camera got a lot easier”. While for GTAs recording took between three and four hours, the LT found that the recording process shortened with experience:

“Depending on the experiment it can be done in one hour, if you are experienced and you know exactly what it is you are going to say”

While initially it was planned for the LT to record all the videos for consistency, when discussing best practice, he suggested a “standard format, but different presenters are ok”.

“If you can, [keep videos] four minutes long, with a friendly, personable, user-friendly presentation style.”

Once the videos had been implemented, several positive observations were made by the module leader and the lab technician. Students came to the labs “more prepared to operate the equipment” and as students knew more operationally, it made GTAs free to act in “an advisory” role.

“They appeared a lot more confident. You feel that they are more prepared, as they’ve seen the equipment on film and straight away you can see themselves familiarising themselves with the equipment and comparing it to the video.” - *lab technician*

“Rather than asking them [GTAs] operational questions they were asking them more intellectually challenging questions” - *module leader*

By allowing students to focus less on operational issues, the course co-ordinators could also improve their own teaching.

“Students were asking [me] a lot of engaging questions, above and beyond the project scope and that pushed me to think about how we can make it more open ended, because students were starting to take interest, they were becoming more engaged and more independent” - *module leader*

The videos also contributed to making organisation of the labs “much more straightforward and simpler to co-ordinate”. More students were able to “finish [their experiments] within three hours”, meaning projects did not overrun, or require rescheduling to complete.

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Videos also had indirect maintenance benefits:

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“Rather than different demonstrators showing different groups of students different ways of using the equipment, which potentially could lead to mistakes and students breaking equipment, the videos feature one person showing students how to [correctly] use the equipment. This saves me time on repairing equipment.” - *lab technician*

In terms of the wider strategy for practical teaching, the success of the approach inspired wider use in future, with much briefer handouts in later years.

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“They [the students] should watch the videos for an operational insight. One which they can watch while they are operating the equipment, so it gives them support in the lab, but also avoids them having to read lots of operational material. Instead they can read lots of interesting technical material that will help them design and shape their project.” - *module leader*

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Reducing the written handout will also help eliminate perceived contradicting information in the handouts and videos, addressing one negative comment from the students’ feedback above:

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“A picture paints a thousand words. It would take 300 words to define what a reactor is, but a video will show you exactly what a reactor is, what a thermocouple looks like, what a stirrer motor looks like on top of a reactor, and [its] assembly all within 30 seconds” - *module leader*

“You can avoid any lack in communication via videos, because you can show what you are doing, how you are doing it and what you can achieve.” - *module leader*

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Ultimately course co-ordinators do not want videos to be the main form of instruction, but to be a “complementary tool”:

“You miss a personal touch in terms of instruction [with videos], small tweaks that you want students to do and that’s why the GTAs are there and they are always going to be there” - *module leader*

“Ultimately what you want is GTAs to be much more intellectually interactive and take out the operational aspect and videos allow us to do that very effectively.” - *module leader*

Graduate Teaching Assistant Perception

Graduate Teaching Assistants are PhD students who are hired on an hourly basis, to act as ‘demonstrators’ of experimental equipment and practical procedures to undergraduate students. GTAs were responsible for producing 60% of the videos made. The GTAs found the longest part of the process to be the script writing and preparation of the videos, with the recording process typically taking between three to four hours. With regards to the filming process one GTA suggested:

“It would be beneficial to have an additional person e.g. narrator helping with the experiment recording as they found it difficult to do both [narrate and carry out the experiment] at the same time”.

GTAs views on the videos were collected immediately in the academic year 2016/17 via a focus group. They noticed a marked difference in student productivity once the videos were released, e.g. risk assessments (the first assessed work for each experiment) improved significantly after the introduction of video instruction and were of much higher quality than in previous years. Mainly they perceived “a change in students’ behaviour, they started to run the labs more independently after watching the videos”, which is in keeping with the student comments. GTAs suggested “there should be a clear differentiation between demonstrational/operational and problem-solving videos” and that problem-solving videos could be produced to address common operational issues, thus “freeing GTAs’ time, making them available for further discussion of theory”.

A further focus group with GTAs from the Foundation Lab (AY 2019/20) was undertaken to explore the extent of these initial observations further, and whether they had any long-lasting effects. For that academic year, students had been instructed to watch videos for all seven experiments in advance of any experimental work. When asked about take-up rate in comparison with the first cohort, the GTAs suggested that the rate had not changed since the initial intervention in 2016/17, “[a] maximum two out of [five or six students in] the group”, “30%” and “30-40%”, and that variation between groups was

down to student engagement, i.e. in groups with more engaged students “the whole group felt obliged to [...] watch the videos”. The excuses given for not engaging included not being aware of the videos’
335 existence, as well as not having enough time to watch them.

When asked to how they could tell the difference between students that had watched the videos and those that had not, the GTAs indicated it was usually easy to tell with reasons ranging from improved practical skills, to increased curiosity and theoretical engagement.

340 “For me, the students just quite clearly could tell how to remove bubbles from a manometer which was something that was covered in the videos.”

“If you knew what the colour change was it meant you’d either read the document or watched the video”

345 “They’re a bit more curious about stuff, so for sure you would know if someone is asking more detailed questions, that they’ve watched the videos.”

“They were more confident... they didn’t need as much help or guidance from me.”

Increased confidence was a recurrent theme cited by the GTAs as a distinguishing performance factor:

“It definitely gave them more confidence in what they were doing”

350 “What I observe also is that if the students watch the video, they are less likely to struggle in the setting up aspect or technical aspect [of the experiment].”

The GTAs still had to spend some time doing traditional equipment demonstration with “30-40 minutes” being typical with up to “one hour [of] demonstration” for some, depending on variations in group ability
355 and preparedness. In order to cater for this, one GTA “created a base 40 minutes introduction walking around the rig”. Despite only having to spend a fraction of the three-hour lab session on demonstration, the GTAs still felt they “need to be available for the whole three hours... if they have any questions because there are a lot of questions”. The GTAs spent the rest of the session “sitting there and observing and maybe giving some suggestions if they [the students] are struggling”.

360 Despite a noted increase in student confidence and curiosity, the GTAs did not believe that access to video instructions could make first year students truly independent:

“I felt like we had to be there all of the time, they didn’t really lead it”.

365 When asked why students in the foundation labs could not be independent, that was ascribed to their previous education where students “are taught in a surface learning approach... within the timeframe of the Foundation Lab you haven’t got the time to change that”. However, this gets addressed through the higher education journey itself, with one GTA remarking:

370 “I have worked with the third years before, for the Discovery Lab, and I can obviously feel the difference. The first years are looking at the SOP like a recipe. But the third years see the videos as a tool.”

While videos can help first years to become more acquainted with the labs, true independence is hindered by deference to the standard Operating Procedure (SOP).

375 “The SOP is like the Holy Grail! They’re in the mind-set that if the video said this, they have to do it.”

It there were minor errors in the SOP, or equipment would break, the students would struggle, and here the GTAs had to step in. Ultimately the GTAs see their role in the Foundation labs “to assist [the students], not hands on, so if they had a slight problem, they can still ask you”. While videos can instruct students on how to carry out an experiment and “what kind of things they should do, they don’t know why... I think the job for the GTA is not only about the steps [of the procedure] but to teach the students, 380 so they understand the knowledge”.

Key Suggestions for Teaching Practice

Based on the qualitative and quantitative data collected in this study, we have assembled a few points 385 of note for readers to consider when implementing a similar approach in their own setting.

- Demonstration videos need to be concise and to the point; they only convey targeted information related to equipment operation. Problem solving videos should be kept separate.
- Videos complement GTAs but cannot replace them.
- Content of videos and handouts need to be perfectly aligned.
- 390 • For effective student engagement, videos need to be short, ideally less than five minutes. Multiple short videos are preferred over one longer one.

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- Clarity and pronunciation can be an issue with an international student cohort, hence annotations or sub-titles are useful.

CONCLUSIONS

This study highlights a paradigm change in experiential learning. Videos, and particularly instructional videos on demand, have been widely used for day-to-day activities from do-it-yourself home improvement to cook recipes. Educational institutions have used videos effectively to deliver online lecture modules and outreach demonstrations. This study highlights a further application for videos to enhance the student learning experience in practical modules. Video-led instructions enabled students to become more confident in their own learning. Videos also reduced demonstration time for course instructors freeing up valuable education time, allowing for more intellectually stimulating discussions regarding the project, context, and wider applicability of the work. Students engaged well with shorter videos, and multiple short length videos covering specific aspect of the experiment were found to be more effective. This study demonstrates the potential for employing videos to transform the role of lab demonstrators to facilitators and ultimately mentors, thereby creating a cohesive enabling environment for independent learning in later years.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX.

Details of Questions asked during different types of focus groups and interviews conducted. (DOCX)

Typical instructional video (MP4)

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