

Full Paper

Abstract

Electronics laboratory work can be very resource-intensive to support, particularly for novice first-year students. This paper describes the motivation, background, development and evaluation of a project focused on developing very high quality laboratory guidance video tutorials that can be richly integrated within both online learning and live laboratory environments for self-directed learning. One insight from the project is the importance of having domain experts performing or directing all aspects of the development: preparing content, presenting, operating cameras, editing and evaluating video materials. Results from formative evaluations on a large first year class show that high quality video-based laboratory guidance materials are popular with students and can make an important additional contribution to laboratory learning by providing a new resource for self-directed learning and improving student-demonstrator interaction in class, particularly for students who are new to the laboratory environment.

Introduction

Engineering students learning their very first foundational concepts require close integration of analytical skills and rigorous hands-on experience and this is recognised in current courses, however student and staff feedback at UNSW Electrical Engineering indicates there is considerable scope for improvement in the first year laboratory learning experience. Specifically, some issues that may be improved include (i) variability in laboratory demonstrator expertise and communication skills, which are not always tailored to students' levels of knowledge, (ii) student understanding of the correct and effective use of specialised laboratory equipment, (iii) the possibility of re-visiting laboratory guidance, particularly fundamental concepts and instructions, and (iv) opportunities for self-directed learning. From a student perspective, demonstrator explanations in the laboratory are not persistent (i.e. cannot be reviewed later), and when there is a group of students around a bench, not everything may be visible. From a staff perspective, there is inefficiency (demonstrators answer same question many times), a lack of well-developed narrative explaining the close integration between theory and lab, which is a problem identified by student feedback as well, and no opportunity for linking on-campus with off-campus laboratory experiences.

Anecdotally, staff often point to the following issues impeding the development of good laboratory skills in first year engineering, apart from the issues relating to learning analytical material: (a) understanding of laboratory equipment, how it operates, and how to make correct and meaningful measurements; (b) understanding what a correct measurement looks like in a typical experiment, and how to interpret it; and (c) precise, comprehensive and professional record-keeping practices in experimental work.

Many sources in the literature point to the benefits of completing preparation before each laboratory (Gregory and Di Tripani, 2012), and the challenges of the high-cognitive-load live laboratory environment, in which students attempt in short periods of time to construct new schema that bridge their analytical and practical understanding of course content (Schmid and Yeung, 2005). Patterson's (2011) evaluation of a chemical engineering-based video laboratory manual showed that students universally found it a positive resource, preferable to a paper-based manual. Although there is significant engineering education literature discussing remotely-operated laboratories (e.g. Almarshoud, 2011; Diaz et al., 2013; Chatterji et al., 2013; San Cristobal Ruiz, E., 2013), there is remarkably little previous work on self-paced video laboratory guidance (Schmid and Yeung, 2005; Dongre et al., 2013), and none describe details of how such materials should be prepared.

Mayer (2008) breaks the key aspects of effective multimedia instruction into (i) reducing

extraneous processing, (ii) managing essential processing and (iii) fostering generative processing. Some implications from these principles for the laboratory context include:

- Aim wherever possible for simplicity, explaining the minimum number of lab concepts with the minimum equipment and elaboration within a single module (achieves both reduction of extraneous material and shorter learner-paced segments)
- Use plenty of pointing, as a means of highlighting essential detail. Learning can be deeper when connections are built between verbal or written and pictorial representations
- Clearly explain the names and characteristics of all equipment used at the beginning of the series
- Use more than one presenter, so that a conversational style develops naturally
- There is mostly no need to add text to multimedia content; this should be replaced by narration wherever possible

Methods

Based on the principles of effective multimedia instructions (Mayer, 2008), a suite of videos of experimental electronics were designed, created and post-produced using multiple viewing angles specifically selected to maximise insight into the laboratory processes and skills being demonstrated. The topics spanned by these videos can be broadly categorised into 2 groups, lab equipment instructional videos and lab experiment videos. The lab equipment instructional videos included detailed practical introduction to laboratory equipment and their correct use in practical lab work. The lab experiment videos included a number of experiments, involving electronic circuits ranging from simple to somewhat complex, designed to teach electrical engineering design and circuit construction conventions, specific laboratory techniques, troubleshooting and engineering skills such as detailed note-taking.

At this stage, the project scope comprises introductory electrical engineering labs covered in the first year of a typical undergraduate program and the content was chosen based on identification of fundamental lab skills for electrical engineers by teaching staff, feedback from students and lab demonstrators. Specifically, the lab equipment instructional videos covered the use of basic electronics lab equipment, namely, the DC power supply, the bench multimeter, the function generator and the oscilloscope. The topics covered in the lab experiment videos are listed in Table 1, designed to be minimal according to Mayer's (2008) principle (above). The lab equipment instructional videos were produced with a single demonstrator, since they focussed only on the operation of the instruments, while the lab experiment videos were produced with two demonstrators each, since these experiments involved practical work, making measurements and note-taking.

Table 1: Sequence of first lab experiment videos produced and the basic electrical engineering skills emphasised in each of them. Note that separate, specific videos (not listed) were created for each type of measurement equipment.

Experiment	Concepts emphasised
Voltage Divider	Analytical link: Ohm's law and how it can be observed physically Introductory circuit construction
	Measurement process: Introductory DC (multimeter) and AC (function generator, oscilloscope) Note-taking through all of the above
Lighting an LED	Analytical link: Ohm's law in a circuit with a non-linear device Measurement process: DC voltage and current Note-taking: Accurate sketching of results
Logic gates	Use of device data sheets: Integrated circuit Circuit design and construction with integrated circuit logic gates Note-taking and analytical link: Truth tables
Transistor switch	Use of device data sheets: Identifying transistor legs Prototyping with transistors Observation of switching behaviour: Transistor in saturation region
RC circuit – Transient response	Experiment design: Use of correct input signal Measurement process: One-shot transient response Note-taking: Graphing of results
Op-amp Amplifier	Analytical link: Voltage gain derivation and choice of resistors Use of device data sheets: Integrated circuit Circuit design and construction with integrated circuit Experiment design: Use of correct input signal Measurement process: Correct calculation of experimental gain
Two stage amplifier (op-amp + transistor)	Circuit analysis Circuit debugging techniques and skills

Given the aim of producing high quality instructional videos for use by first and second year students, the following requirements were identified that guided the choice of recording equipment: (a) high resolution recordings were desired; (b) multiple items of lab equipment had to be recorded simultaneously rather than multiple separate, sequential recordings from different angles; (c) an unobstructed view of the prototyping board was essential; (d) an unobstructed and clear view of the lab notebook was required to show circuit diagram, record taking, relevant equations, etc.; (e) suitable mounting equipment to keep cameras fixed and vibration free was critical; (f) ease of operation of mounted cameras was highly desirable. Based on these requirements and the content of the videos, 5 camera angles were chosen for simultaneous recording and these are listed in Table 2 and shown in Figure 1. The Panasonic HC-V750M video camera was chosen based on its capabilities. Specifically, the ability to record high resolution video (Full HD - 1080p), suitable focal length range in the in-built lens and the ability to remotely operate the cameras via the Panasonic app on android and iOS. The remote operation ability was particularly convenient for controlling the cameras mounted on the overhead boom arms (difficult to reach) and ensuring the camera positions were not disturbed due to manual handling over the course of a video shoot. The in-built microphones on the cameras were used to record voice as well (the best audio stream from the 5 different cameras was chosen in post-production).

Table 2: List of camera angles recorded simultaneously

Camera Angle	Camera mount
Front-on view of both presenters (scene)	Standard tripod
Front-on view of oscilloscope	Standard tripod
Front-on view of power supply, multimeter and function generator (equipment)	Standard tripod
Top-down view of prototyping board	Tripod with adjustable camera boom

Top-down view of notebook

Tripod with adjustable camera boom

Four high-achieving undergraduate students were chosen as presenters with a pair of them presenting each experiment. This team provided some redundancy (in case one person was not available) and a sense of collegiality, by rotating presenters through the various recordings. Pairing presenters achieved the conversational style advocated by Mayer (2008). A fifth undergraduate student was carried out all post-production. All five students were involved in each recording session, with two as presenters and the other three as the recording team. The recording sessions were also closely supervised by the authors. Including the student responsible for post-production during the recordings proved to be very efficient, since a consistent vision for what the final video should be like was carried through from the video shoot to post-production and the requirements for specific post-production could be taken into account quite easily during the shoot.

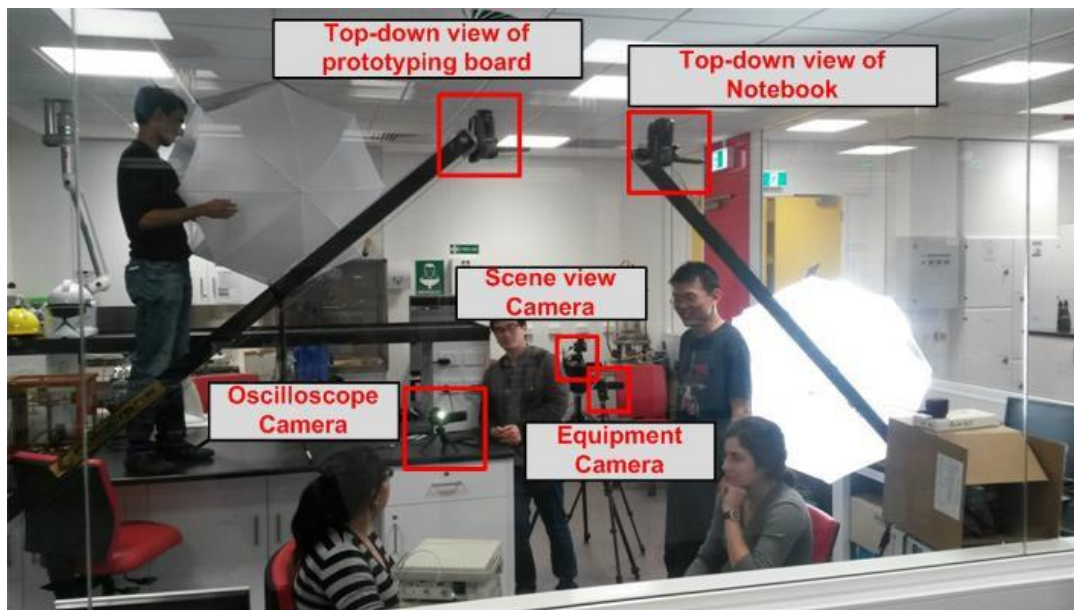


Figure 1: Photograph of the recording setup highlighting the 5 camera angles.

The final stage of the recording process was the post-production stage, where appropriate sections from the five video streams were combined to provide the best possible views over the video (refer to Figure 2 for examples of some views after post-production). A second critical aspect of post-production was the introduction of suitable graphical and textual overlays to support the explanations given by the presenters – experience showed that this was the best way to achieve the “pointing” referred to in Mayer’s (2008) principles. Finally, during the post-production stage, the audio recorded by all five cameras was compared and the best audio stream, in terms of clarity of the presenters’ voices, chosen as the final audio stream. All post-production was carried out using Final Cut Pro software, based on the team’s familiarity with the software.

Evaluation

The results of two formative evaluations are described in this paper. One is a heuristic evaluation by experts (three laboratory demonstrators and two experienced academics external to the project), who assessed the materials created according to a series of criteria motivated by Mayer’s (2008) multimedia instruction criteria and commented on how students and demonstrators used them. The video materials comprised 22 separate files, with lengths between 1:10 and 4:18, averaging about 100 seconds, and were made available in low (480p) and high (1080p) resolution in streaming format from <http://eemedia.ee.unsw.edu.au/Laboratory/index.htm>.

The other is a questionnaire answered by students and laboratory demonstrators from a first-year Electrical Circuits course with 199 students, which was designed to understand how the introduction of the video laboratory guidance materials affected the learning and teaching behaviours within the course, and to elicit feedback on the utility of the materials. In this course, the videos were recommended as a resource in a general way, but were not directly integrated into the teaching, and students were not given any specific instructions on how they should be used. Demonstrators were also instructed not to make any positive or negative comments about the videos when interacting with students. The reasoning behind this approach was to observe what natural changes in learning and teaching behaviour the videos elicited in students and demonstrators respectively.

The formal questionnaire comprised questions on student difficulties in the lab, the usefulness of written lab guidance materials provided, interaction with demonstrators (before/after provision of videos), usage of the videos, attitude towards the videos and behaviour changes induced by the availability of the videos, and was completed by 52 students¹ of a first-year Electrical Circuits course, at the completion of the lecture schedule.

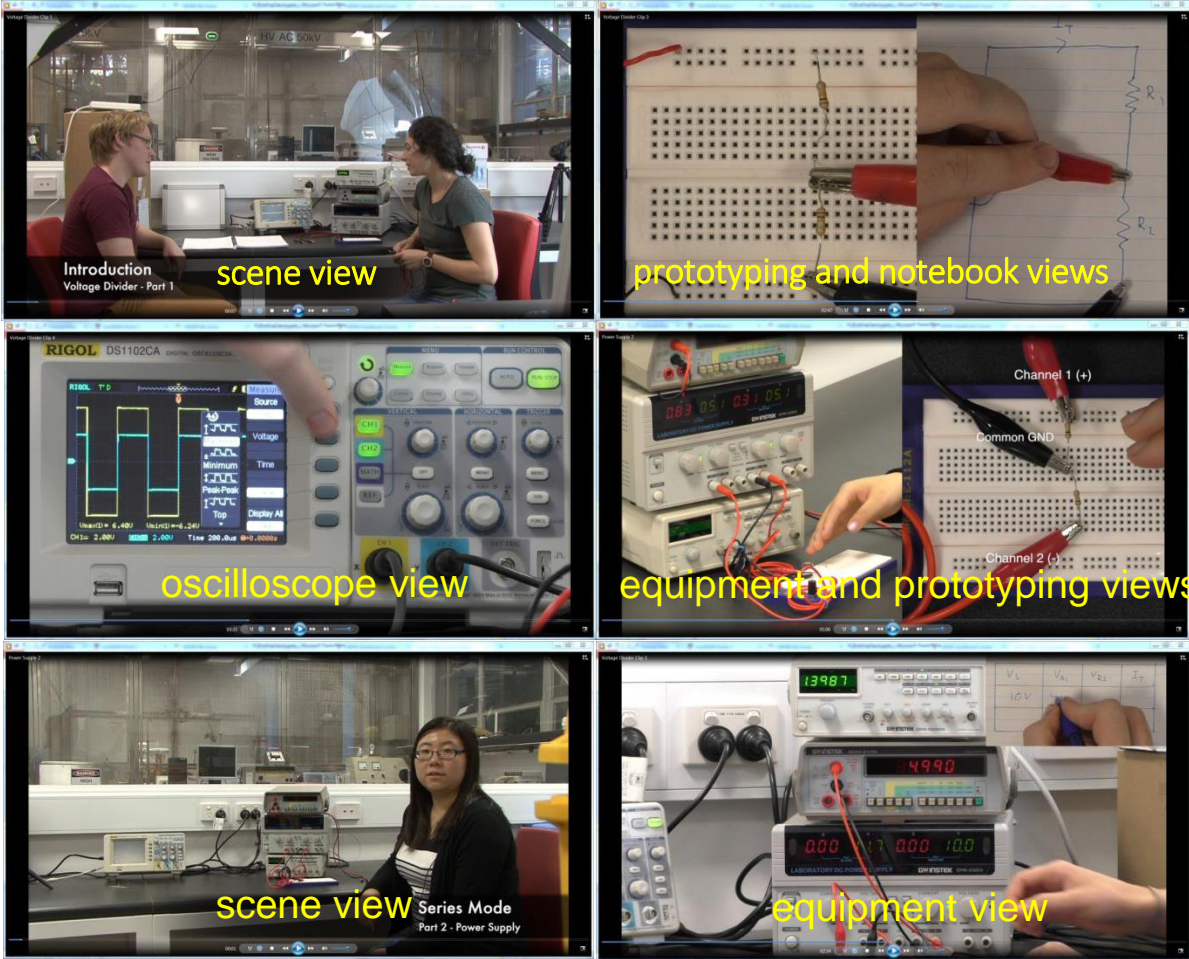


Figure 2: Screen shots of example post-produced video, showing different camera angles and post-production approaches

Results and Discussion
 Heuristic Evaluation

As explained above, during the first use of the lab guidance videos, neither students nor demonstrators were given specific instructions on how to use them, with the intention of

observing how they naturally used the materials. Based on informal demonstrator responses and student written responses, student-demonstrator interaction improved, with students who

¹ The low response rate was attributed to the fact that the lecture syllabus had concluded and the class in which the survey was administered was a revision class.

used the videos commenting that they were able to ask more informed questions during the lab, and demonstrators spontaneously recommending that students used them to aid learning. Demonstrators commented that by contrast, in the laboratory students did not once refer to the text-based manual on how to use lab equipment that was provided with the introductory laboratory notes (even though this was part of their laboratory instruction, given before the lab guidance videos were made available): “Quite a few students found the lab procedures a bit confusingly written”. Some demonstrators used the lab guidance videos to prepare for laboratory teaching, to gauge in advance the kind of problems that might arise. Other comments included: “I think the videos are good because they start from basic aspects of the measurement devices and go step by step to higher levels”. Suggestions by academic staff for improvements included additional information on a few technical details, explaining why particular choices had been made in the measurement process, and overlaying circuit diagram graphics on the prototyping view. These will be implemented in post-production.

Questionnaire

Students were positive in their questionnaire responses, although 37% of students surveyed had not used the video materials at the time of the survey². Among those who had used the videos, more than 60% watched them more than once. As seen in Fig. 3, many respondents felt that the video materials changed their laboratory experience (“neutral” seemed mostly to reflect those who did not use the video), and based on their open-ended question responses, these were positive changes. A common comment was that after viewing the videos, students felt more confident and better equipped to ask more specific questions in the laboratory, e.g. “can understand what [demonstrators] are saying more when they respond to our questions”, “the videos allowed me to ask more specific questions. I could easily recognise if I was using anything improperly”, “I now know what I’m messing up . . . [demonstrators gave me] less condescending responses”, “[the videos changed my questions] because I knew how the equipment was supposed to work”, “they have reduced the number of questions I would need to ask”, “it was very practical in that I was seeing what the demonstrators were doing”, “I don’t really have to ask them again on how to use the equipment”, “if I consulted them, I probably would have asked more informed questions”.

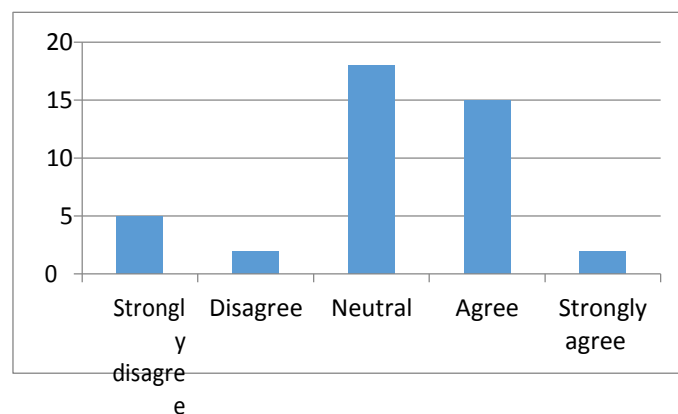


Figure 3: Responses to the question “The videos changed what I did in the lab, or how I went about the lab”

There was a preference for video-based lab guidance materials over written lab guidance materials (Fig. 4 – again “neutral” seemed mostly to reflect those who did not use the video), which is probably not a surprise, and an overwhelming 95% and 97% of respondents felt that video-based lab guidance should be adopted in future Electrical Circuits courses and in future engineering courses respectively. An example comment was: “it is easier to learn how

² It is expected that this proportion would drop in later instances of courses, if lab guidance materials were formally included as part of the laboratory instructions, or if course staff emphasised the value of their use.

to use the [equipment] while you are looking at it and what it does, rather than reading material”.

Anecdotally, a large number of students used the materials during self-directed preparation for their laboratory exam³, where previously very few revision opportunities existed: “they helped summarise before the exam”, “best – being able to study at home”, “helps me to pass the lab exam”, “you can learn even if you didn’t finish the lab”. In terms of requests for improving the videos, in most cases students requested additional videos of more complex examples; these are currently in development.

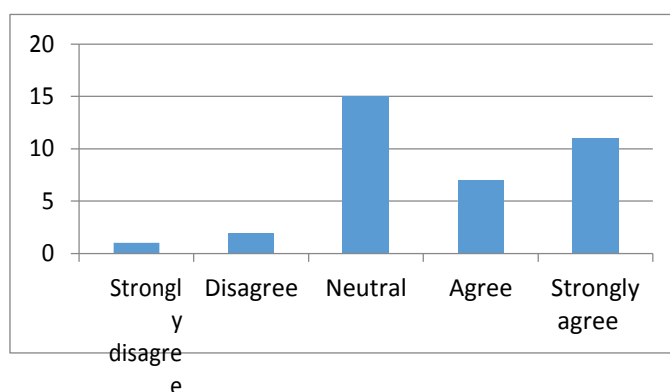


Figure 4: Responses to the question “I prefer the video to the [written] material provided earlier in the course”

Principles of Multimedia Instruction

Among Mayer’s principles of multimedia instruction, “reducing extraneous processing” seems to have been achieved, by limiting each video to the smallest possible subset of terms, concepts and skills, and by drawing attention to the key ideas through the presentation, the choice of camera angle and/or the post-production graphic overlay. “Managing essential processing” was also achieved by using spoken rather than textual explanations, using learner-paced video modules, and by carefully and gradually introducing key terms and concepts. “Fostering generative processing” was achieved both through the conversational style of presentation and by the integration of words and pictures, e.g. through split video showing lab notebooks and circuits/measurements, and through post-produced text overlay on the videos.

Conclusion

Results from the evaluation conducted to date support the value of high quality multi-view video-based laboratory guidance, for preparation, in-lab guidance and laboratory skills revision, however a more detailed and larger-scale study will be needed to quantify this further. Three key findings emerged from the study reported in this paper: (i) high definition multi-view video based materials are preferable to written instructions in guiding students in the use of electronics lab equipment (supported by the questionnaire responses), (ii) the video materials have the potential to change student-demonstrator interaction in classes, improving the experience for both, and (iii) students appreciated the new possibility for self- directed learning that the videos represent. Although the initial plan was to use a professional audiovisual production team, the authors found that the importance of employing electrical engineering academics and students as the production team – for presenting, recording and editing – cannot be overstated in producing high quality, relevant materials.

³ This aspect was not covered by the questionnaire because this hadn’t previously been considered as a primary focus for the video materials.

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Acknowledgements

The authors gratefully acknowledge the efforts of the recording and editing team: David Vang, Sandra Pulver, Ryahn Rahme, Angus Fletcher, Alison Kong and Ruichen Zhao.

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