UNSW Learning and Teaching Grants and Fellowship Program

Final Report

Grant: Strategic Educational Development

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A Next-Generation Laboratory-Enhanced Learning Paradigm

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1. Acknowledgements

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2. List of acronyms used

HD -- High Definition (digital recording)

3. Executive summary

This project specifically addresses the learning of foundational practical skills in electrical circuits mainly in the first year of study, by more than 1200 engineering student each year. Electrical circuits are small and highly detailed, and the use of complex lab equipment needs to be mastered to make good measurements on them and hence learn from the experience. Large teams of sessional demonstrator staff are needed, however their live explanations are not persistent, cannot be observed easily by large groups of students, are repetitive (need to be given many times in the same class), and vary in quality even after training. To date, students have had minimal materials for self-directed study – only written lab guidance which is hard to interpret, and videos from other institutions which are of poor quality, relevance or clarity of explanation. This includes lab videos from prestigious engineering universities such as MIT.

Following the principles for effective multimedia instruction (Mayer, 2008), a suite of digital recordings of *experimental electronics* were designed, created and post-produced using five high definition (HD) cameras with viewing angles specifically selected to maximise insight into the laboratory processes and skills being demonstrated. The content included detailed, practical introductions to laboratory equipment, the correct use of equipment for taking meaningful measurements, electrical engineering design and construction conventions, specific laboratory techniques, troubleshooting, and engineering skills such as quality, detailed note-taking – a vastly increased scope relative to existing video content. The presenter team were high-achieving undergraduate students, closely supervised by the investigators, and stringent production values were observed. The intended audience was first- and second-year students of electrical engineering (later extended to third-year signal processing students). Throughout the project, the focus was not only on producing the course materials, but on building insight into how materials of this kind should be created in order to maximise their utility during teaching.

An evaluation spanning the development and use of the digital recordings across five medium/large first-year engineering courses (more than 1000 students total) is described.

Outcomes:

- A suite of introductory laboratory guidance digital recordings – 27 for on-campus labs and 8 for low-cost off-campus (remote) laboratory work.
    - Integration of these into major engineering service courses in electrical engineering (underway)
- A suite of 108 introductory MATLAB laboratory guidance short digital recordings
    - Integration into introductory digital signal processing and control systems courses (underway)
- A set of procedures and principles for development of multi-view, multi-instrument lab recordings
- Survey-based student evaluations and heuristic staff evaluations of the above
- Publications (*Proc. Australasian Assoc. for Engineering Education*, 2015; also *IEEE Trans. Education* paper in preparation)
- Dissemination via UNSW and Faculty of Engineering L&T Forums (in progress)

Recommendations: Results from the evaluation strongly support the value of high quality multi-view digital recording-based laboratory guidance in large first-year engineering courses, for preparation, in-lab guidance and laboratory skills revision. The authors found that the importance of employing electrical engineering academics and students as the production team – for presenting, recording and editing in context – cannot be overstated in efficiently producing high quality, relevant materials.

4. Key stakeholders

Ray Eaton (Associate Dean Education, Engineering) – guidance throughout on major issues faced by students and teaching staff, structure of project, team composition, oversight
Russell Waldron (eLearning Advisor, Science) – initial guidance on digital recording production, equipment, storyboarding, learning segment duration, software and logistics.
Branislav Hredzak, Jayashri Ravishankar (EE&T academic staff with ELEC1111 teaching experience) – initial advice on course-specific issues, key learning problems faced by students, key deficiencies in lab instruction within the course
David Taubman, Torsten Lehmann and Hadis Nosratighods (EE&T academic staff with deep electronics and design teaching experience) – evaluation of resources created from staff perspective
Sandra Pulver (EE&T student representative[1]) – evaluation of resources created from student perspective

5. Project objectives, approach and evaluation

5.1 Aims

The main objectives of this project were to (i) pilot a framework for rich resource development for independent learning specifically in the electrical engineering context, to move face-to-face class time towards a higher value, more interactive, more challenging experiences, with no long-term increase in cost, (ii) implementing the framework for a large first year electrical engineering course, (iii) evaluating the implementation and reflecting on the possibilities for further improvements and for innovative teaching delivery modes, and (iv) disseminating the key findings and experiences within UNSW. Secondary objectives included providing externally available hands-on independent learning with global reach and creating high quality teaching resources that help to promote UNSW.

5.2 Intended Outcomes

The project was designed to deliver:

a) a literature review of laboratory-based learning, to inform this project and to accompany the knowledge base to be transferred to other disciplines.
b) a complete set of high quality laboratory guidance materials in the form of short modularised digital recording recordings to support and enhance student learning;
c) a detailed rich resource linking the recordings with associated learning material facilitating self-directed laboratory study;
d) a detailed road map of how and when the resources are most appropriately used across a 12 week semester;
e) a preliminary full trial of the technology-enhanced laboratory resources
f) a detailed 'how-to' guide for other disciplines interested in adopting the paradigm.
g) a presentation and/or workshop explaining, the pros and cons of the paradigm and its implementation.

5.3 Conceptual Framework

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 answering 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.

[1] Note that only one student representative was employed both due to the volume of materials to review and because the resources were produced largely *by* a student team. Further exposure to students will facilitate more evaluation.

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 good 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, and this project specifically, 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; replace this by narration wherever possible

To summarise, the conceptual framework is built around flipping the most generic, labour-intensive part of laboratory instruction; providing high quality, clear reference explanations of key concepts which do not exist in any publicly or privately available video resources; and applying Mayer's principles of effective multimedia instruction to laboratory learning resources.

5.4 Materials and Production Methods

An important aspect of this project was the choice to simultaneously record five different angles. It was a very deliberate choice, based on (i) the need to capture the scene, prototyping board, measurement equipment (x2) and lab notebook simultaneously and (ii) the desire to allow the user to switch between angles during playback. Detail is critical; HD digital recording is essential and taking the more common audiovisual approach of recording different angles sequentially could very easily introduce errors or inconsistencies into the explanation.

Five Panasonic HC-V750M video cameras were chosen for the project, based on the ability to record high resolution video (Full HD - 1080p) with vivid colour and suitable focal length range in the in-built lens. An important feature of these cameras was the ability to remotely control the cameras via the Panasonic app on Android and iOS, since operation of five cameras (two situated a metre above the presenters) is logistically challenging. The five cameras, four tripods, two jib cranes and two sets of lights (Fig. 1) were not particularly expensive, representing 10% of the overall budget, and have already been used in other contexts since the recording ceased.

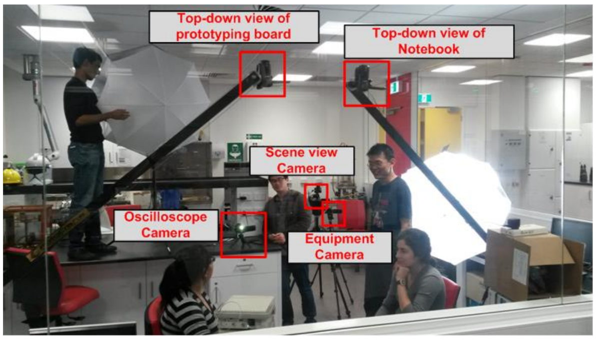

Figure 1. Photograph of the recording setup highlighting the 5 camera angles.

Key insights from the planning and recording process included:

- The need for a quiet environment where the equipment can be left set up for long periods of time (months) – this saves a huge amount of set-up/packup. Ideally a permanent studio would be good, but the intended outcomes can be achieved with the current infrastructure.
- The use of a team of presenters was very important: it gave a lot of momentum to the project, allowed redundancy in case people were away, gave a good atmosphere to allow everyone to feel comfortable on camera, made the operation of five cameras easier and was good for diversity (students not bored as easily as watching one person). Choosing members who are familiar with content, are engaged and will contribute well was critical
- The use of student presenters was very helpful: it gave the resources the right perspective, the language was better tuned to the audience, and the level of technical presentation was closer to the skill level of audience
- Pair presentation was definitely better than monologue. One person can point to the circuit diagram or notebook to show what is being measured, while the other handles the circuit and measurement equipment. Taking turns gives time to mentally prepare for next part of an explanation, and allows interjection at key points and banter to keep the explanation interesting (important for engagement).
- Positioning cameras further away was important, since this was more natural for presenters and it was easier to keep everything in the field of view without cameras getting in the way of each other.
- There were lots of issues with keeping everything visible and not occluded. Equipment was angled relative to presenters, to allow camera placement. The lab notebook was stuck down to stay aligned correctly. During practical work, the presenter's hands often occluded the prototyping board or the controls of the measurement equipment – it took many iterations to learn how to hold hands during recording.

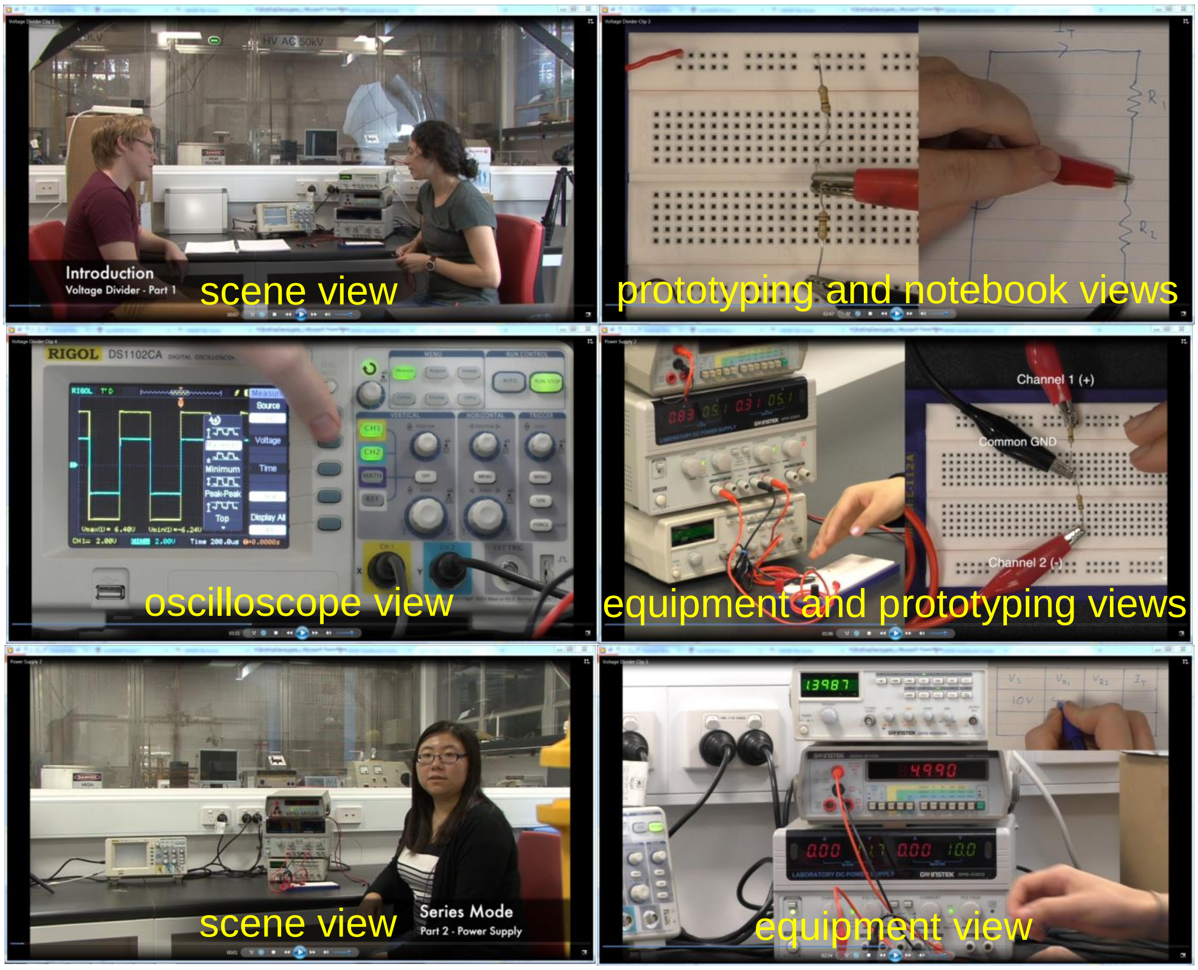

Figure 2. Example HD multi-view laboratory guidance digital recording resources. The previous state of the art, from MIT, showed only prototyping and multimeter views with confusing cabling, covered very little content and did not explain measurement techniques, relation to theory or best practice in laboratory note-taking. The depicted digital recordings were developed and produced jointly with experienced *student* demonstrators, producing reference explanations that first-year students can easily relate to.

5.5 Evaluation Methods

The main form of evaluation was a questionnaire answered by students from multiple medium/large first-year electrical circuits courses, which was designed to understand how the introduction of the digital recording laboratory guidance materials affected the learning and teaching behaviours within the course, and to elicit feedback on the utility of the materials. The survey comprised questions on student difficulties in the lab, the usefulness of written lab guidance materials provided, usage of the digital recordings, attitude towards the digital recordings and behaviour changes in students and laboratory staff induced by the availability of the digital recordings, and were completed towards the completion of the lecture schedule. In future, usage data will be collected via Moodle or other means.

Among the various courses, the digital recordings were recommended as a resource in different ways. In particular, in the first offering (ELEC1112 S1 2015), they 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 digital recordings when interacting with students. The reasoning behind this approach was to observe what natural changes in learning and teaching behaviour the digital recordings elicited in students and demonstrators respectively. In later courses, students were instructed to make as much use of the digital recordings as possible, and demonstrators were encouraged to familiarise themselves with them and use them in their teaching as they saw fit.

5.6 Evaluation Results

Overall, the surveys across all five courses evaluated overwhelmingly supported the use of the HD multi-view digital recording lab guidance resources in future instances of the course and other courses (Figures 8 and 9). The responses on how the resources were used were very illuminating, since this kind of resource has never previously been available to students of electrical circuits. Although students collectively used the resources before, during and after labs and before laboratory exams, the preference of most students was for either lab preparation and/or laboratory exam[2] preparation (Figure 4). The former result is encouraging, suggesting that students will adopt the resources to arrive at the labs better prepared, to enhance their lab learning, in line with the aim of this project. The latter result is interesting because students have never previously had any materials they could use for *self-directed* preparation for laboratory exams, while there has always been demand for self-study materials. It is also encouraging to see that across all courses, 50% or more of students who used the resources used *each* resource more than once, exactly addressing the identified problem of the non-persistence of live explanations.

There were more mixed responses about how much the student-demonstrator interaction changed as a result of the resources (Figures 5 and 6), but in many cases students were conscious of their in-laboratory learning experience being different. A common survey comment was that after viewing the digital recordings, 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”.

Table 1. Key details of courses evaluated. Note: “Resp.” indicates the number of respondents to the questionnaire, “% used” indicates the proportion of respondents who used the resources.

Course	Name	Timing	Size	Notes	Resp.	% used
ELEC1112	Electrical Circuits	S1 2015	199	Theory-based course, traditional delivery, scaffolded lab program	52	62
ELEC1111	Elec. and Tele. Eng.	S2 2015	572	Theory-based course, traditional delivery, scaffolded lab program	46	91
ELEC1111	Elec. and Tele. Eng.	Summer 2015/2016	29	Theory-based course, blended delivery, scaffolded lab program	6	100
ELEC1111	Elec. and Tele. Eng.	S1 2016	310	Theory-based course, traditional delivery, scaffolded lab program	49	94
ENGG1000	Eng. Design and Innov.	S1 2016	136	Skills-based course, problem-based learning, fast lab introduction	39	69

[2] Laboratory exams are one-off live practical exams held towards the end of semester, as a means of individually assessing students’ practical skills, since first-year lab work is performed in pairs.

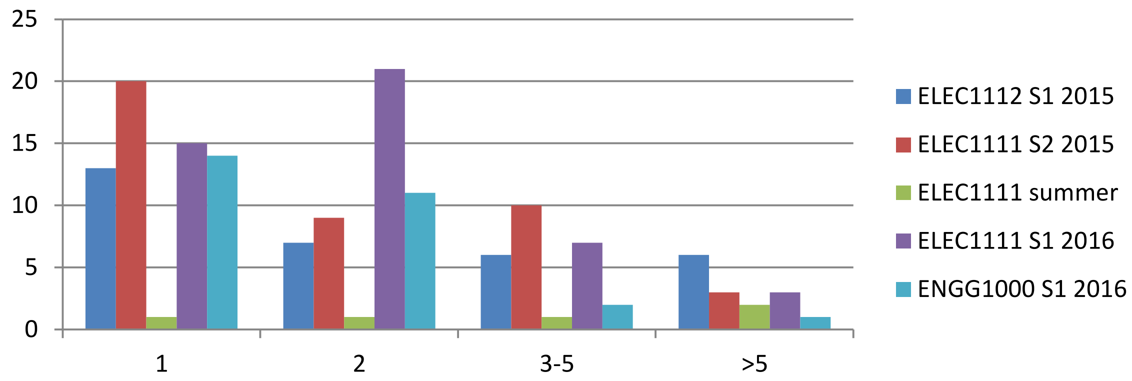

Figure 3. Number of times *each* lab guidance digital recording was used by a survey respondent

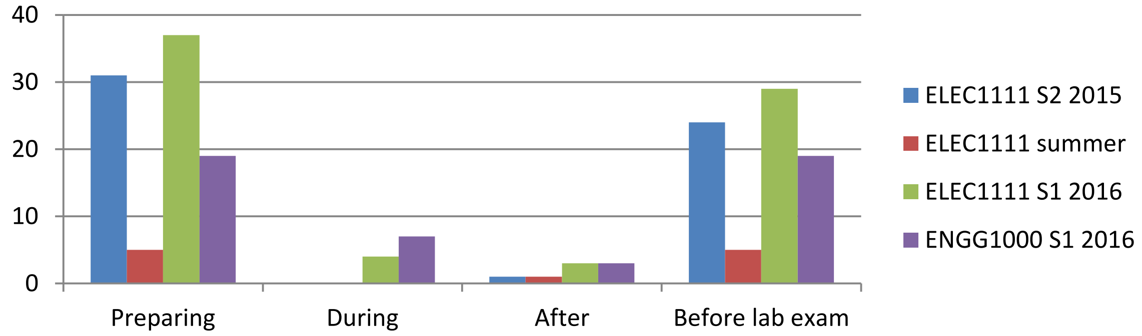

Figure 4. Context in which lab guidance digital recording was used: ‘Preparing’, ‘During’ and ‘After’ all refer to regular laboratories.

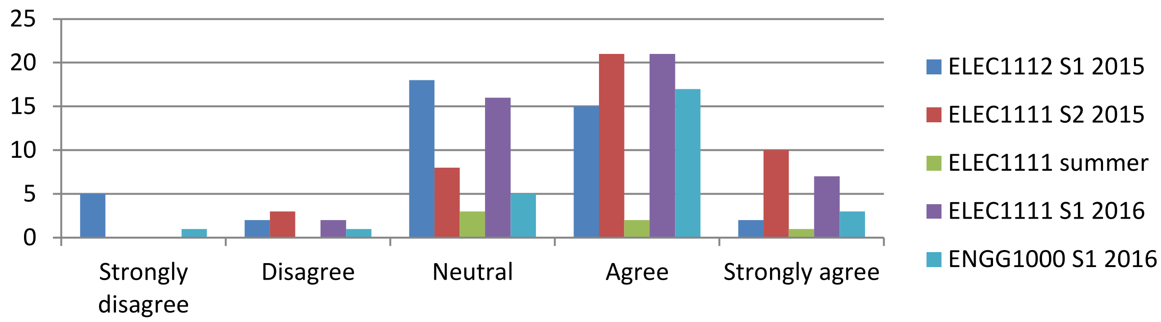

Figure 5. Survey responses to the statement “The digital recordings changed what I did in the lab, or how I went about the lab”

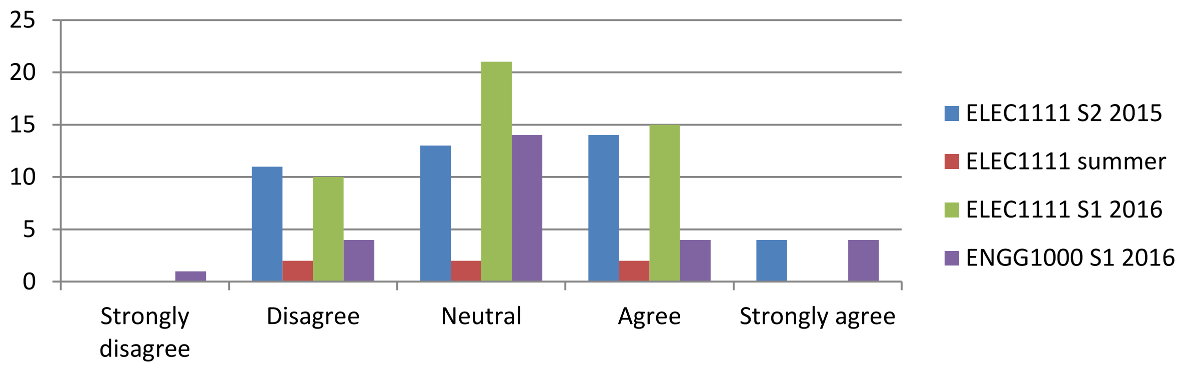

Figure 6. Survey responses to the statement “The digital recordings influenced the kinds of responses I received from lab demonstrators”

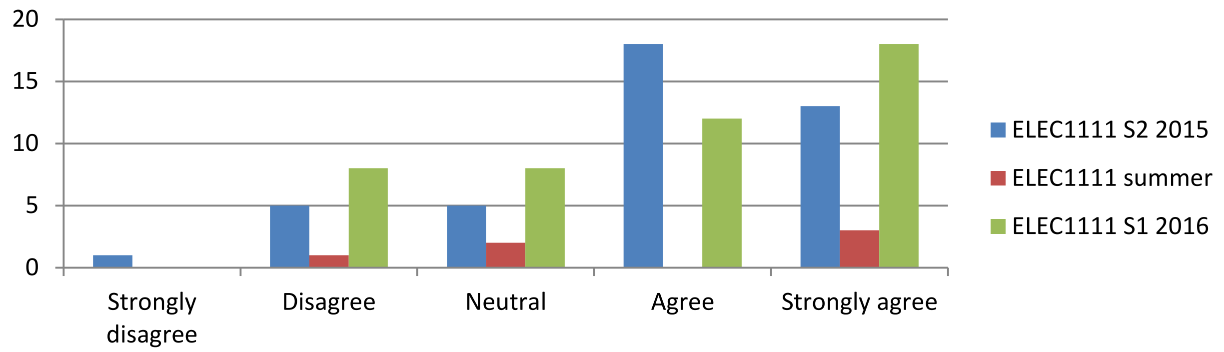

Figure 7. Survey responses to the statement "I prefer these digital recordings to the written lab manual resource"

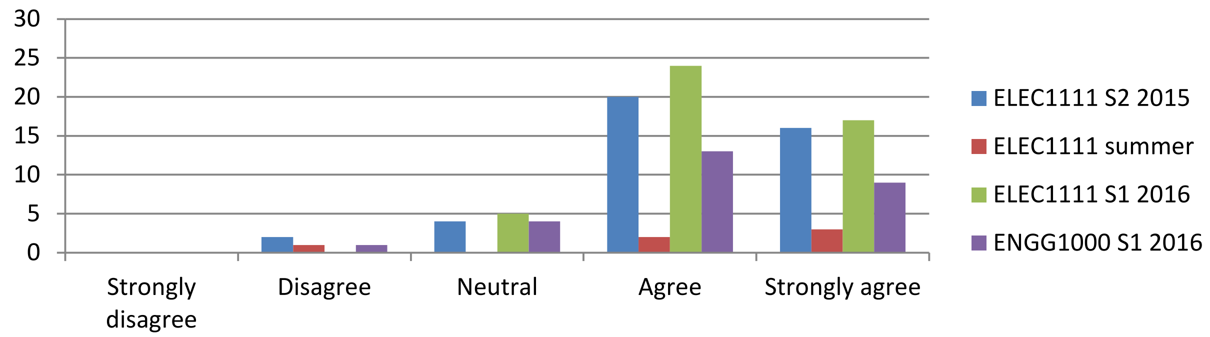

Figure 8. Survey responses to the statement "I would recommend that these digital recordings be used in the future for this course"

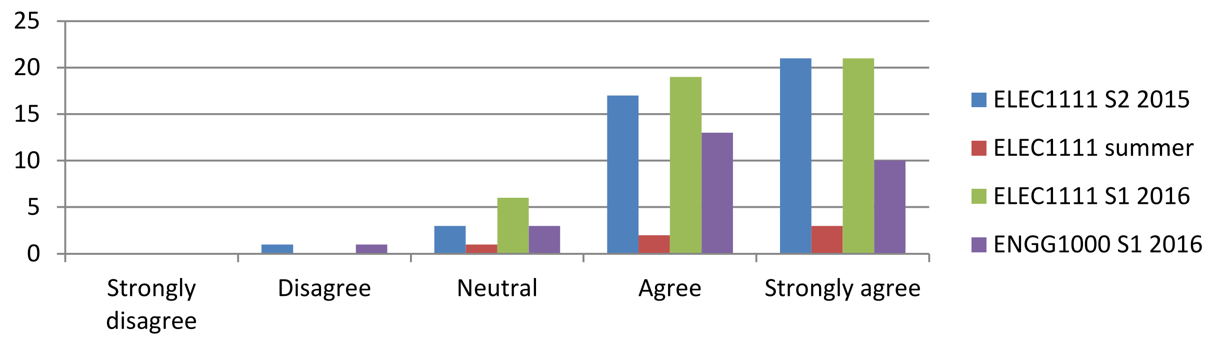

Figure 9. Survey responses to the statement "I would like to see similar lab guidance digital recording material in future courses"

6. Project outcomes and impact

The major outcomes of this project were:

- A literature review on laboratory-based guidance, preparation of practical multimedia educational content and laboratory in engineering education – Outcome (a)
- A complete set of post-produced, peer-reviewed, high-definition, multi-view laboratory guidance resources in modular form, spanning first-year (and some second-year) electronics concepts using on-campus equipment, similar concepts using low-cost measurement equipment for off-campus use, and introductory MATLAB programming – Outcome (b) and more
- Preparation of digital recording materials for future student-controlled multi-view video players[3]
- Two papers (one published, one in preparation) explaining how the above materials were applied to large-class first-year teaching – Outcome (d)
- Trial and evaluation of the resources in five course offerings with different class sizes and teaching modes – Outcome (e)
- Insights into how to develop these kinds of materials, currently being prepared from notes into both a formal written and a presentation (forthcoming UNSW L&T Forum, Faculty L&T Seminar) – Outcomes (f) and (g)

The impact of this project on the university has been:

- Significantly improved course materials in direct support of the 2025 Strategy of blended learning by default, which have provided 20-60min worth of enhanced laboratory learning per week per student, with no additional timetabling or space requirements.
- Development of a novel form of educational resource, which objectively exceeds the presentation quality of all others for the purpose of first-year electrical engineering laboratory instruction (previous best practice was probably MIT's Electronic Circuits laboratory videos), thereby providing international leadership.
- Adoption of these resources in three different courses to date (serving more than 1200 students in total), including large service courses within Engineering.
- Analysis and development of the laboratory teaching mode based on the resources, to improve the quality and consistency of laboratory education on a large scale.
- Dissemination of the project insights via scholarly publications and through internal Learning and Teaching events (in progress).

7. Sustainability of outcomes

The high-definition multi-view laboratory guidance resources have been post-produced and peer-reviewed with the intention of long-term use and deep integration with multiple first-year courses. Their production represents by far the most labour-intensive aspect of the enhancement of laboratory learning, and from this perspective the gains made by the project are not only sustainable, but might be extended through future experimentation with course delivery modes. For example, further embedding of the resources (e.g. into Moodle modules under development as part of the DVCE-assisted transition of ELEC1111 to blended mode) is a much more modest effort which could see more structured use by virtually all students. The resources from this project are therefore extremely sustainable. Additionally, the equipment and expertise from this project are now available to other groups within UNSW interested in similar development, so the sustainability of this less common kind of educational development has been improved by the project. The School of EE&T has already planned further internally-funded projects based on the equipment and expertise gained from this project to extend the outcomes and impact on student learning experience.

[3] Note that outcome (c) was not fully achieved, because after extensive searching, no widely-adopted methods for embedding links in temporal hypermedia (video), or widely-adopted tools for playing multi-view video were found. However all video was collected and post-produced specifically to allow real time view-switching, once this becomes widespread (YouTube is currently experimenting with this, for example).

8. Insights and Recommendations

During the project, which was unlike any other previously undertaken by any of the project team, the following insights were gained:

- Development team: 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
- Enhanced, self-directed laboratory work: Resources of this kind provide new possibilities for self-directed laboratory learning, where OH&S allows it. Students used the resources in ways that no other existing resource could be used, to prepare for lab classes and lab exams.
- Persistence, efficiency and consistency of laboratory instruction: This is the first form of high fidelity laboratory instruction in the School which is persistent, and can be reviewed multiple times according to student preference. Lab demonstrators reported that they were able to “flip” generic explanations for equipment, measurement processes and lab professional practice expectations, outsourcing these normally highly repetitive explanations to the multi-view digital recordings. The digital recordings provide reference explanations which are used by both demonstrators and students alike, reducing the variance in explanation between demonstrators.
- Sessional staff training: The digital recording resources are now part of demonstrator training in early-stage electronics courses.
- Quality of laboratory learning: Many students reported that the questions they asked laboratory staff, and the responses they received, were different as a result of the multi-view digital recordings. For those students, this project has shifted the precious, time-limited live laboratory experience up to a higher level of learning, since the most basic concepts and questions are resolved prior to arriving in the lab.

The following recommendations are made:

- Schools or faculties with significant laboratory components in their large courses, which have a significant need for sessional laboratory staff who may be repeating basic explanations frequently, may stand to gain significantly from next-generation laboratory learning projects of this kind[4].
- Based on digital recording resources of this kind, laboratories should be available to students for informal learning, where OH&S requirements permit.
- A significant time commitment by all staff involved in the process is needed, however given this the total cost is in the order of $10K per hour of fully post-produced digital recording, rather than significantly more. Contrary to initial expectations, it seems that very little of the process can be easily outsourced to staff who are not subject matter experts. For the most complex multi-view recordings, we were fortunate to have a team of committed staff who made time available during their evenings; without this, progress may have been very much slower.
- HD cameras are now sufficiently affordable and convenient that recording multiple views (even as non-expert users) is increasingly feasible. This is particularly beneficial in the lab setting.
- One of the challenges in scoping this project was that (by definition) no team members had experience in this kind of production, and hence it was very difficult to estimate the effort (and hence cost) that would be needed. This led to a lengthy suspension of funds mid-project, after the project appeared to be underspending. While the project outcomes were ultimately not adversely affected, other approaches to the funding could be considered for projects where there is little prior experience, e.g. funding in two phases, with the pilot phase designed to measure the real cost of all project components and hence more accurately scope the second (main) phase.

[4] The School of Physics has produced a fairly similar set of resources that are well received by first-year students, although the scope of these are more limited in many respects.

9. Financial statement acquittal of funds

	Budget $	Expenditure Actual $	Committed[1] $	Balance $
PERSONNEL				
Polished professional delivery of the materials in the lab under lecture staff supervision	$53.2K	$53.2K		
Video recording and complete post-production support	$15.8K	$15.8K		
Subtotal	$69K	$69K		
PROJECT SUPPORT				
Recording equipment/tools	$10K	$10K		
Subtotal	$10K	$10K		
PROJECT ACTIVITIES				
Ongoing testing and validation with selected students	$7.6K	$7.6K		
Subtotal	$7.6K	$7.6K		
TOTAL	$86.6K	$86.6K		

[1] Committed expenditure represents funds for purchases or personnel costs that have already occurred and are awaiting invoices/payments

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