Full Paper

Introduction

The teaching laboratory plays an important role in engineering education with laboratory skills being recognised when programs are accredited by bodies such Engineers Australia and ABET. While the development of engineering capability via practice has always played a role in educating future engineers, researchers have found it difficult to measure learning in the laboratory (Cunningham, 1946; Feisel & Rosa, 2005; Hofstein & Lunetta, 1982; Majerich, 2004). In 2012, a three day colloquy was undertaken to develop a set of learning objectives for the laboratory. Thirteen learning objectives were agreed upon that students should achieve throughout an undergraduate engineering degree (Peterson & Feisel, 2002). This achievement was important because studies carried out, such as that by Casas and del Hoyo (2009), found that simply having a laboratory component was no guarantee of learning. However, the laboratory is more than just gaining knowledge, it is about doing, and learning through experiences. A measurement tool by Salim, Rosmah, Hussain, and Haron (2013) called Measuring the Learning Outcomes of Laboratory Work (MeLOLW) was developed by combining the thirteen laboratory learning objectives to the cognitive, psychomotor and affective domains associated with Bloom's taxonomy (Krathwohl, 2002). The MeLOLW instrument was verified by only a small sample. Therefore, in this study the MeLOLW instrument is checked against a new sample and used as a measure of learning.

In higher education student opinion is used to help guide progress, evaluate teachers, resources, facilities and learning. The goal of such activities can include trying to improve the student experience, to gain a competitive advantage in attracting students, and improve learning (Ambikairajah, Sethu, Eaton, & Sheng, 2014; Nikolic, Ritz, Vial, Ros, & Stirling, 2015). The problem with student evaluations is that the data can be dangerous if applied without fully understanding the instrument being used. In addition, do students have the ability to make such judgements? Questions like this have resulted in over a thousand studies on student evaluations (Spooren, Brockx, & Mortelmans, 2013). Unfortunately, even with so many research studies greater understanding is needed, especially when trying to determine the relationship with learning.

This paper advances the work of previous studies that use student evaluations to try and improve the laboratory experience. The first study by Nikolic, Vial, Ros, Stirling, and Ritz (2015) developed a student evaluation and training program to improve the performance of sessional laboratory demonstrators. The study found that over time as the demonstrators were trained and mentored student satisfaction increased. The second study by (Nikolic, Ritz, et al., 2015) developed a student evaluation instrument to monitor student satisfaction with the laboratory experiments and facilities. The study found that the quality of the experiments (activity and clarity) was a major driver of student satisfaction. Other similar studies have explored how learning resources can improve student satisfaction (Nikolic, 2015; Vial, Nikolic, Ros, Stirling, & Doulai, 2015).What these studies do not do well, is measure how the evaluations relate to learning. Therefore this study will use a modified version of MeLOLW to investigate the relationship of student evaluations and learning in the laboratory across the cognitive, psychomotor and affective domains.

Method

The laboratory component of two engineering courses were selected for this study. The first course (ECTE233) was a second year digital hardware laboratory. The course contained a mixture of simulation and practice based learning. For most experiments the students would commence by simulating various integrated circuits (ICs) and purpose built circuits using Multisim by National Instruments. This would then be followed with the physical construction of the circuits using digital IC's. The course had six experiments with three hour durations, conducted fortnightly over the session. A laboratory practical examination was held during the official examination period. This was the first time a laboratory exam had been undertaken for the course.

The second course (ECTE363) was a third year telecommunications laboratory. All experiments focused on using TIMS (hardware for the simulation of telecommunications signals and systems) (Vial et al., 2015). There was no software component to this course. The course had five laboratory sessions with three hour durations, conducted fortnightly over the semester. The students were expected to complete at least five different experiments. A laboratory exam was held during the sixth laboratory session. The laboratory experiments were used to introduce many concepts that were not covered in lectures or tutorials.

At the start of the first laboratory session for both courses a self-assessment was undertaken. Students were requested to rate their knowledge on a scale from zero to five, with zero reflecting no knowledge to five reflecting extreme confidence. Students that agreed to participate in the research were requested to include their student number for identification. At the end of the last laboratory session (sixth laboratory session for ECTE233 and fifth for ECTE363) the same self-assessment activity was repeated. During the second last laboratory session the laboratory and sessional teacher surveys were conducted. Students that participated in the research were requested to include their student number for identification.

The data for the self-assessments, student evaluations and laboratory exam were matched using the student number and then the responses were de-identified for analysis. A total of 125 complete responses were matched across the two subjects as summarised in Table I.

TABLE I: Student Participation

Course	No of Students	Completed at Least One Component	Data Match to All Four Components
ECTE233	114	106	73
ECTE363	64	61	52

ECTE233 consisted of one small laboratory class with one demonstrator and three large classes with two demonstrators. ECTE363 consisted of five small laboratory classes each with one demonstrator. The allocation of sessional laboratory demonstrators was assigned to maximise the diversity of teaching experience across the laboratory classes. A summary of the laboratory class information is shown in Table II with each demonstrator assigned a different number.

TABLE II: Laboratory Demonstrator Allocation and Class Size

Course	Demonstrator/s	Class Size
ECTE233	Dem01	15
ECTE233	Dem01, Dem02	29
ECTE233	Dem03, Dem04	37
ECTE233	Dem05, Dem06	35
ECTE363	Dem07	11
ECTE363	Dem07	15
ECTE363	Dem08	7
ECTE363	Dem08	16
ECTE363	Dem09	15

The self-assessments were undertaken using a modified MeLOLW survey, shown in Appendix A. The original MeLOLW instrument contained nine measures for the cognitive domain, and seven for both the psychomotor and affective domains. After reviewing each of the measures within each domain it was decided to alter the wording to better position the statements within the context of the laboratory experiments the students were undertaking. The laboratory component of each course has slightly different learning objectives.

Adjustments to the MeLOLW questions were made to be compatible to the learning objectives of the two courses. The wording of the questions was also changed from being generalised to being specific to avoid any ambiguity for the students. For example in digital circuits there is no unit of measurement, simply one or zero. The greatest changes occurred for the cognitive domain. The modified and original questions are shown in Appendix A. Students were asked the question, “How would you rate your ability to…” for each measure on a scale from 0 – I have no idea at all to 5 – I am extremely confident.

Results and Discussion

The first analysis was to check the reliability of the survey after the modification of the questions. This was achieved by comparing the Cronbach’s alpha coefficients to those of the MeLOLW instrument. As is shown in Table III the coefficients of the modified instrument, both at the first and last experiment, are high and comparable to MeLOLW. A value greater than 0.70 is considered appropriate. This shows that there is some flexibility in the wording of the measures.

TABLE III: Cronbach’s Alpha Coefficients for Learning Instrument

Learning Domain	MeLOLW	Modified First Experiment	Modified Last Experiment
Cognitive	0.901	0.83	0.83
Psychomotor	0.853	0.89	0.86
Affective	0.774	0.88	0.87

The next step was to confirm the number of components/factors within each learning domain. The default method of determining factors is via Kaiser Criterion by observing if the eigenvalues are greater than one. However, literature suggests that it should not be the only criterion as it tends to over extract factors (Lance & Vandenberg, 2009). Therefore, four different checks were used; Kaiser Rule, parallel analysis, optimal coordinates and acceleration factor. Table IV lists the results of underlying factors behind each score.

TABLE IV: Factor Analysis of the Learning Instrument

	First Experiment				Last Experiment			
Learning Domain	**Kaiser Rule**	**Parallel Analysis**	**Optimal Coordinates**	**Acceleration Factor**	**Kaiser Rule**	**Parallel Analysis**	**Optimal Coordinates**	**Acceleration Factor**
Cognitive	2	2	2	1	2	2	2	1
Psychomotor	1	1	1	1	1	1	1	1
Affective	2	1	1	1	1	1	1	1

Table IV indicates that three of the tests (Kaiser, Parallel and Optimal) show that the cognitive domain has two factors present. This is shown in both the self-assessment activities. To determine the two factors a principle component analysis was undertaken. This is shown in Figure 1, suggesting that measures eight and nine for the cognitive domain are separate to measures one to six. Upon reading the questions, this is highly possible as questions eight to nine differ due to their concentration on writing skills.

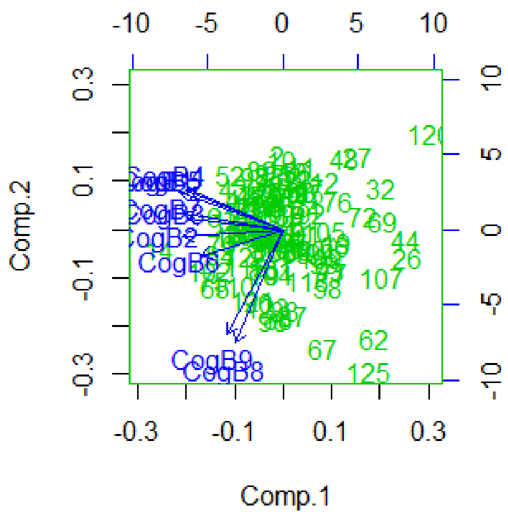

Figure 1: Principle Component Analysis of Cognitive Domain

With the factor analysis completed, the relationship between learning and the student evaluations was examined. Learning was measured by comparing the difference in learning from the self-assessment conducted at the start of the first experiment to the self-assessment of the last experiment. It is important to note that this measure has no indication of actual learning. However, students are not really aware of actual learning when completing the evaluations. The other limitation with the research is that the student may over or under estimate their ability before actually undertaking the laboratory experiments. This may skew the difference in learning between the two self-assessments. The relationship was investigated using:

- L : All six laboratory evaluation questions outlined in (Nikolic, Ritz, et al., 2015)

- L1: Only questions one to three of the laboratory evaluation with a focus on the experiments
- L2 : Only questions four to six of the laboratory evaluation with a focus on Laboratory facilities
- D1: The lead laboratory demonstrator questions outlined in (Nikolic, Vial, et al., 2015)
- D2: The assistant laboratory demonstrator (where applicable)

The student evaluations are converted into a weighted-average score to allow for easy comparison. Full details about the evaluation scores can be found in the respective journal papers (Nikolic, Ritz, et al., 2015; Nikolic, Vial, et al., 2015). Table V shows the relationship of the perceived learning students gained across the three learning domains compared to the student evaluations. The table shows the effect of 1 score increase of each learning domain compared to L, L1, L2, D1 and D2. The values are significant at the 5% level and are indicated by the asterisks. The relationships that were found to be significant are between the increases in learning across the cognitive and psychomotor domains with the student evaluations of the laboratory experiments. The student evaluations on the laboratory facilities or demonstrators shows no significant relationship. In addition, changes in the affective domain also have no effect on the student evaluations. It is important to note that the sample covers only two laboratory courses with a total of 125 students. As a result significance could increase with a larger sample, but this does provide some evidence of the importance of both cognitive and psychomotor learning to achieve high satisfaction for laboratory experiments.

TABLE V: Relationship between Learning and Student Evaluations

Factor	L	L1	L2	D1	D2
DiffCog	3.095* (0.024)	4.167* (0.016)	2.021 (0.187)	-2.065 (0.309)	2.539 (0.487)
DiffAff	1.370 (0.325)	1.957 (0.265)	0.783 (0.613)	-2.581 (0.206)	2.054 (0.490)
DiffPsy	2.197* (0.046)	2.834* (0.042)	1.560 (0.205)	-0.659 (0.686)	-0.151 (0.953)

The factor analysis indicated that the cognitive domain has two factors. The first was based on analytical skills (Q1-7), the other on writing skills (Q8-9). Table VI shows the relationship of the cognitive domain on the student evaluations across the two factors. The data indicates that only the analytical skills, and not the writing skills, are what influence student opinion of the laboratory experiments.

TABLE VI: Effect of Factors in the Measurement of Cognitive Learning

Factor	L	L1	L2	D1	D2
DCog Q1 to Q7	0.340* (0.031)	0.452* (0.021)	0.222 (0.205)	-0.331 (0.151)	0.216 (0.620)
DCog Q8 and Q9	0.382 (0.543)	0.529 (0.502)	0.2329 (0.741)	1.459 (0.115)	0.885 (0.574)

The final test was to compare the student self-assessment to the performance in the laboratory exam. Table VII shows this relationship comparing the exams separately and simultaneously. A negative sign shows a decrease in laboratory score. The data suggests that the only relationship that exists between students perceived learning is for analytical skills within the cognitive domain. In this comparison the psychomotor skills are no longer significant. This is a common phenomenon and is important, as the effect on laboratory exams is really due to improvements in cognitive skills and not in psychomotor skills. For Q1 to Q7 an increase in difference of cognitive skills leads to an increase in the laboratory exam score, whereas for Q8 and Q9 an increase leads to decrease in laboratory exam score. This suggests that the lab exam score only tests students' analytical skills and therefore an increase in 'writing' skills does not help in doing well in the laboratory exam.

There were a number of problems associated with the laboratory exams. The ratio of equipment to students is often a problem. This means that multiple repeated sessions of the laboratory exam is needed. While the exam questions are changed slightly with each repetition, the message is spread amongst students about what is in the exam. Analysis of the lab exam cohorts showed that for both courses the mean laboratory exam mark increased in each subsequent running of the session. The ECTE233 exam was highly skewed towards full marks, students either knew or did not know the fundamentals. The ECTE363 exam had a greater distribution of marks. The other major problem about comparing the laboratory exam marks is that students cram extensively beforehand. Therefore the level of knowledge can be substantially different from the time student evaluations are undertaken. As a result the data in Table VII can only be used as a very rough guide.

TABLE VII: Self-Assessment vs Laboratory Exam Performance

Factor	**Lab Exam - separately**	**Lab-Exam simultaneously**
DiffCogQ17	*1.301 (<0.001)*	1.520 (>0.001)
DiffCogQ89	-3.090 (0.006)	-2.8417 (0.011)
DiffAff	3.637 (0.147)	-0.2143 (0.947)
DiffPsy	4.670 (0.019)	-2.112 (0.4610)

Conclusion

This study investigated how perceptions of learning across the cognitive, psychomotor and cognitive domain influenced student evaluations in the laboratory. A modified MeLOLW instrument was used and verified as a reasonable measure of learning across the three domains. Factor analysis found that two factors were present within the nine learning measures contained within the cognitive domain. While the study was only conducted across two courses with a small sample, evidence suggested that student evaluations of the laboratory experiments was influenced by students' perceived analytical skills gained in the cognitive domain and psychomotor skills. This supports the study by Nikolic, Ritz, et al. (2015) that found the laboratory experiment (activity and clarity) played an important role in student satisfaction. No relationship with learning was found with the laboratory facilities and demonstrators. Student evaluations are very complex and this data is only one small jigsaw piece in a very large puzzle. This research is currently being conducted on more courses to obtain a more definite understanding. While many laboratory activities, especially simulated ones focus on the cognitive domain, the outcome from this study suggests that developing psychomotor skills is seen as important by students and experiment design should incorporate this where possible. In addition, this study has highlighted that more work needs to be carried out on how to effectively and fairly test students psychomotor ability, instead of concentrating on cognitive learning.

Appendix A

Self-Assessment Questions

Measure	MeLOLW	ECTE233 Adapted	ECTE363 Adapted
Cognitive 1	Improve knowledge and theory learned in class	Understand the operation of digital IC's and other digital hardware?	Understand the operation of TIMS hardware?
Cognitive 2	Help verify theory learned in class	Design circuits (physical or simulation) to verify the operation of digital hardware?	Verify telecommunications theory via TIMS equipment?
Cognitive 3	Improve ability to use formulas in solving problems / questions related to theory	Use Boolean algebra to simply circuits?	Use TIMs equipment to solve problems?
Cognitive 4	Improve ability to use the correct unit for the measured values	Read and understand IC datasheets?	Read and understand TIMS datasheets?
Cognitive 5	Help to develop basic statistical technique (i.e. draw graph and chart)	Draw a truth table or timing diagram for a digital circuit?	Draw graphs, signals and charts related to telecommunications?
Cognitive 6	Improve understanding about safety in the lab	Understand lab safety for a digital hardware lab?	Understand lab safety for a telecommunications lab?
Cognitive 7	Improve ability to analyse / discuss experimental result	Analyse truth tables and timing diagrams?	Analyse/discuss the results from a telecommunications experiment?
Cognitive 8	Improve ability to write the conclusion of the experiment	Write a conclusion for an experiment?	Write a conclusion for an experiment?
Cognitive 9	Improve ability to write laboratory report	Write a lab report?	Write entries into a logbook, in a professional manner?
Psychomotor 1	Improve ability to conduct experiments	Correctly conduct an experiment on digital hardware?	Correctly conduct an experiment on TIMS hardware?
Psychomotor 2	Improve ability to select appropriate instruments	To select appropriate instruments for both the input and output of your digital circuit?	To select appropriate instruments for both the input and output of your TIMS circuit?
Psychomotor 3	Improve ability to plan experimental work	Plan experimental work on digital hardware?	Plan experimental work on TIMS hardware?
Psychomotor 4	Improve ability to construct circuits	Construct a working digital circuit?	Construct a working TIMS circuit?
Psychomotor 5	Improve ability to connect instruments	Connect meters, displays and other instruments to a digital circuit?	Connect meters, displays and other instruments to a TIMS circuit?
Psychomotor 6	Improve ability to operate the instrument (i.e. select proper range)	Use a Wishmaker/Prototyping board?	Operate instruments (TIMS, CRO etc.)?
Psychomotor 7	Improve ability to take the reading of the instruments	Ability to take the readings of the output of digital circuits?	Ability to take the readings from the CRO?
Affective 1	Improve team working skill	Solve digital hardware problems with others?	Solve telecommunications problems with others?
Affective 2	Improve communication skill	Communicate (written and orally) a digital hardware solution?	Communicate (written and orally) a telecommunications solution?
Affective 3	Improve ability to learn independently	Solve digital hardware problems on your own?	Solve telecommunications problems on your own?
Affective 4	Improve ethics (i.e. plagiarism, copy other students results)	Consider ethical issues in the digital hardware laboratory?	Consider ethical issues in the telecommunications laboratory?
Affective 5	Improve creativity	Creatively use digital hardware to solve a problem?	Creatively use telecommunications hardware to solve a problem?
Affective 6	Learn from failure	Learn from failure (when your circuit does not work)?	Learn from failure (when your circuit does not work)?
Affective 7	Improve motivation	Motivate yourself to learn about digital hardware in the laboratory?	Motivate yourself to learn about telecommunications hardware in the laboratory?

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