A European vs Australasian Comparison of Engineering Laboratory Learning Objectives Rankings

S. Nikolic [1]
University of Wollongong
Wollongong, Australia
http://orcid.org/0000-0002-3305-9493

T. F. Suesse
University of Wollongong
Wollongong, Australia

S. Grundy
University of New South Wales
Sydney, Australia

R. Haque
University of the Sunshine Coast
Sippy Downs, Australia

S. Lyden
University of Tasmania
Hobart, Australia

G. M. Hassan
University of Western Australia
Perth, Australia

S. Daniel
University of Technology Sydney
Sydney, Australia

M. Belkina
Western Sydney University
Sydney, Australia

S. Lal
Curtin University
Perth, Australia

***Conference Key Areas**: 9. Virtual and Remote Labs & 16. Curriculum Development, Engineering Skills, Lifelong Learning.*

---

[1] Corresponding Author

S. Nikolic

sasha@uow.edu.au

doi:10.5821/conference-9788412322262.1253

Keywords: *Engineering, Laboratory, Learning Objectives, Skills*

ABSTRACT

Learning objectives are important as they provide direction to teaching staff towards what content should be taught, what activities should be undertaken and what assessments are to be used to confirm understanding. Two decades ago, the evolution of new learning modes such as recorded, remote, and simulation/virtual started the research process to define and better understand learning objectives in the teaching laboratory. Much is still to be learnt about laboratory learning objectives including which are most important, and if what is deemed important is universal. For example, do academics in Europe and Australasia align in which objectives are most important and which are not? To answer this question, European and Australasian engineering academics were asked to rank laboratory objectives across the cognitive, psychomotor, and affective domain using a predefined tool called Laboratory Learning Objectives Measurement. A total of 113 academics from Australasia and 25 from Europe responded to the survey. A statistical analysis was conducted to compare the rankings. The findings from this survey show that substantial alignment occurs across the cognitive and psychomotor domains but differs across the affective domain.

1 INTRODUCTION

1.1 Background

The engineering laboratory has always played an important role in preparing engineering graduates for their careers. Advancements in technology and industrial requirements continue to drive its importance, regardless of its mode of delivery [1, 2]. Systematic literature reviews show that laboratory learning can take place in various modes such as face to face, simulation/virtual and remote; and that learning occurs across the cognitive, psychomotor, and affective domains [3, 4]. COVID19 in particular caused many universities to alter their approaches in how they conducted their laboratory classes [5]. Academic staff did the best they could to make the most of a difficult situation right across the world, accelerating the transition to different laboratory learning modes. With the speed of such change, it is important for academic staff to reflect on the most important laboratory objectives to ensure that the objectives drive the implementation, and not the other way around.

The definition of thirteen key laboratory objectives was established in 2002 [6] and has played an important role in directing the learning outcomes for laboratory research in the last two decades. Researchers have been building upon this foundation to better refine and measure laboratory learning. One such refinement is the Laboratory Learning Objectives Measurement (LLOM) instrument as defined in [7]. The authors have used this instrument to explore if there is a commonality to recognise which are the most important objectives that need to be facilitated in laboratory learning.

This work creates the foundation for a future study being prepared by the authors that will compare objective rankings across disciplines. Due to the overweight of responses from Australasia, an understanding of location differences is necessary. Therefore, the first step is to determine if location altered rankings. For example, there are some major cultural and lifestyle differences between Europeans and Australasians. It would be interesting to know if differences in international location would influence ranking decisions. Therefore, this study explores the LLOM ranking relationships across continents. It seeks to answer the research question '*how do Australasian and European academics rank laboratory objectives compared to the international community?*'.

1.2 The LLOM instrument

Learning in the laboratory can be connected across the cognitive, psychomotor and affective domains [7]. This is because when thinking of a traditional laboratory, students must undertake activities like applying, analysing, and evaluating information (cognitive); imitate, manipulate, and articulate with their hands (psychomotor); and attend, respond and value with their presence (affective). The LLOM instrument combines the 13 objectives listed in [6] with the Blooms Taxonomy level descriptors to provide a holistic list as provided in Table 1.

It is important to note that while a separation exists, learning domains cannot be isolated from each other because almost all learning activities involve more than one domain. The objectives used allow universal application across different engineering courses and disciplines. Key words within the text of an objective have been written in italics that allow modification to match the required context or discipline. Any related word can be used, not just the sample words given for context. For example, the objective P1 written as 'Correctly conduct an experiment on [*course equipment/ software name- e.g. power systems*]?' Could be modified to be 'Correctly conduct an experiment on control systems' or 'Correctly conduct an experiment on hydraulics'.

The instrument was explained to participants taking part in the research. Examples such as the one above, were used to demonstrate how the objectives could be tailored to any particular course by swapping out the italicised words. It was the responsibility of each participant to consider each statement within the context of the course/s they teach.

Table 1. Laboratory Learning Objectives Measurement Items

Domain	Item	LLOM Objective
Cognitive	C1	Understand the operation of *equipment/software* used within the laboratory
Cognitive	C2	Design *experiments/models* (physical or simulation) to verify course concepts
Cognitive	C3	Use engineering tools (e.g. [*name of hardware/software used*]) to solve problems
Cognitive	C4	Read and understand *datasheets/circuit-diagrams/ procedures/user-manuals/help-menus*
Cognitive	C5	Draw & interpret relevant charts, graphs, tables & signals
Cognitive	C6	Recognize safety issues associated with laboratory experimentation
Cognitive	C7	Analyse the results from an experiment
Cognitive	C8	Write a conclusion summarizing your findings from an experiment
Cognitive	C9	Write a *laboratory report/entry into a logbook* in a professional manner
Psychomotor	P1	Correctly conduct an experiment on [course *equipment/ software name- e.g. power systems*]
Psychomotor	P2H	Select and use appropriate instruments for the input, output and measurement of your *circuit/system*
Psychomotor	P2S	Select appropriate commands and navigate interface to *simulate/program* a *model*
Psychomotor	P3	Plan and execute experimental work related to this course
Psychomotor	P4	*Construct/code* a working *circuit/simulation/program*
Psychomotor	P5	Interpret sounds, temperature, smells and visual cues to diagnose faults/errors
Psychomotor	P6H	Operate instruments (e.g. [*equipment name*]) required for experimentation
Psychomotor	P6S	Operate software packages (e.g. [*software name*]) required for *coding/simulation*
Psychomotor	P7	Take the reading of the output from *circuits/ instruments*
Affective	A1	Work in a team to conduct experiments, diagnose problems and analyse results
Affective	A2	Communicate laboratory setup, fault diagnosis, readings and findings with others
Affective	A3	Work independently to conduct experiments, diagnose problems and analyse results
Affective	A4	Consider ethical issues in laboratory experimentation and communication of discoveries
Affective	A5	Creatively use *software/hardware* to design or modify an experiment to solve a problem
Affective	A6	Learn from failure (when *experiment/simulation/code* fails or results are unexpected)
Affective	A7	Motivate yourself to complete experiments and learn from the laboratory activities

2 METHODOLOGY

A multi-institution and multi-disciplinary research team was assembled to investigate the research question. Members of the team reached out via direct email and social media in 2021 to their university, research and professional contacts within the field of engineering to answer a survey created in Qualtrics. The survey required participants to rank in order of importance (1 = highest ranked) the multi-domain objectives as listed in the Laboratory Learning Objectives Measurement (LLOM) instrument as outlined in [7]. Participants were required to rank the objectives from most important (ranking = 1) to least important. To determine if any of the rankings remained unchanged, a fixed initial ranking was used based on the order as listed on this page. None of the rankings were left in the default state for the responses analysed.

Approximately 3,000 academics from all continents were invited to participate in the survey with 219 survey commencements and 160 completions. From this, 113 responses came from Australasia and 25 from Europe. While higher number of survey responses were anticipated, as the numbers suggest it was difficult to encourage participation, especially outside of Australasia. European responses came from Finland, France, Germany, Ireland, Portugal, Serbia, Slovakia and Spain. Attempts to gain responses from other European countries were not successful. The sample size for each European country was too small for analysis, but reasonable as a collective to obtain a European perspective. This imbalance creates the need of this research to understand if location-based differences existed.

3 RESULTS

The platform R version 4.05 was used for the statistical analysis with the results shown in Tables 2 (cognitive), 3 (psychomotor) and 4 (affective). The data was analysed in three groups, international (all data from across the world), Australasia and Europe. The sample size for Europe was not high enough to also look at differences between majors. Rankings were determined using averages. The lower the number, the more academics ranked the objective as being more important than objectives with a higher average. In brackets, the 95% confidence interval (CI) is shown. To determine if a statistically significant difference in average values occurs, the 2 confidence intervals must not overlap. Such differences to the international collective are highlighted in green.

In the last column, the one-way analysis of variance (ANOVA) is applied, this examines whether for a particular objective (e.g. C1), the mean responses are different across the groups, i.e. if shown p-value is less than 5%, then responses differ across groups for that question, otherwise not. A multivariate analysis of variance (MANOVA) was applied to determine if there is a statistical difference overall between locations. The p-value for Table 2 is 0.05763, Table 3 is 0.1238 and for Table 4 is 0.4452. This indicates if the overall responses differ across groups.

Each table also provides a visual representation of the objectives in ranking order. Visual representations can help develop a better understanding of statistical data. Colour coding is used to show how the collective ranking, differs across the groupings. For example, in Table 2, C1 is given the colour light blue. The different ranking of C1 for each group can be easily observed in the table by following the colour trend.

3.1 Cognitive Domain

Table 2 showcases the average values and rankings for the cognitive domain. It can be seen that across the three comparison groups there is substantial alignment in ranking order.

Table 2. Learning Objectives Cognitive Domain (Averages With 95% Confidence Interval) And Ranking Order

Obj.	International	Australasia	Europe	ANOVA
C1	3.11 (2.79,3.42)	3.05 (2.68,3.43)	2.80 (2.09,3.51)	0.560476
C2	3.31 (2.92,3.69)	3.38 (2.90,3.86)	3.48 (2.64,4.32)	0.856811
C3	4.06 (3.69,4.43)	4.28 (3.82,4.75)	3.12 (2.34,3.90)	0.029015
C4	5.50 (5.14,5.86)	5.42 (4.99,5.84)	5.60 (4.62,6.58)	0.71859
C5	5.10 (4.84,5.36)	4.86 (4.55,5.17)	6.16 (5.48,6.84)	0.000537
C6	6.23 (5.85,6.61)	6.35 (5.92,6.78)	6.08 (5.06,7.10)	0.596898
C7	3.86 (3.54,4.18)	3.82 (3.43,4.21)	3.92 (3.10,4.74)	0.832927
C8	6.54 (6.22,6.85)	6.57 (6.20,6.93)	6.28 (5.29,7.27)	0.529588
C9	7.29 (6.98,7.61)	7.27 (6.89,7.64)	7.56 (6.76,8.36)	0.504093
Rank				
1	C1	C1	C1	
2	C2	C2	C3	
3	C7	C7	C2	
4	C3	C3	C7	
5	C5	C5	C4	
6	C4	C4	C5	
7	C6	C6	C6	
8	C8	C8	C8	
9	C9	C9	C9	

The most important cognitive objective is C1 '*understand the operation of equipment/software used within the laboratory*' and was consistent across all groups. This result is not surprising as engaging with hardware/software is core to laboratory work.

The least important item is C9 '*Write a laboratory report/entry into a logbook in a professional manner*'. C8, another cognitive writing-based objective was ranked second last. Interestingly, while lab reports and writing are deemed as least important, the work by Nikolic, Ros [4] found that they were one of the most used assessment types. This provides a strong case of the need for further investigation.

The only major difference identified between the three groups is that the Europeans valued the laboratory objective C3 '*Use engineering tools to solve problems*' higher. This difference was found to be statistically significant. They valued solving problems as more important than design (C2) and analysis (C7). This provides a future research opportunity to find out why this is the case. While C4 and C5 were also interchanged, within the overall positioning this can be seen as negligible. Therefore, it is possible to conclude that regardless of location, ranking order across the cognitive domain is mostly aligned.

3.2 Psychomotor Domain

Table 3 showcases the average values and rankings for the psychomotor domain. Across the three comparison groups a complete alignment in ranking order was achieved. Some of the items had statistically significantly greater weight but remained consistent in ranking order. This suggests that regardless of location, there is a strong consensus of which objectives in the psychomotor domain are most and least important.

The most important objective being (P1) '*Correctly conduct an experiment on [course equipment/ software name]*' and the least important being (P5) '*interpret sounds, temperature, smells and visual cues to diagnose faults/errors*'. The importance of P1 appears self-explanatory, success comes from carrying out an activity correctly. This is a core outcome of laboratory work.

However, the lack of importance given for troubleshooting is a curious observation. P5 has substantial overlap with cognitive skills and is complementary to items C1-C4. It extends beyond the cognitive by considering the actual practice of using the tools to undertake the fault finding. For example, using and reading the display or hearing a beep of a multimeter on an electrical circuit, or moving a hand over an item to feel that it is heating up.

Much engineering practice revolves around knowing how to fix things. If one knows how to fix things, that demonstrates a full/deep understanding of the operation of equipment/software (highest ranked in the cognitive domain). Previous work [8] has highlighted the importance of fault-finding ability on the student experience and understanding, therefore it is possible to assume that the relationship between the two items should be stronger. This is another avenue for further investigation.

Table 3. Learning Objectives Psychomotor Domain (Averages With 95% Confidence Interval) And Ranking Order

Obj.	International	Australasia	Europe	ANOVA
P1	2.46 (2.19,2.73)	2.52 (2.17,2.88)	2.28 (1.77,2.79)	0.5432
P2H	4.13 (3.78,4.48)	4.04 (3.63,4.44)	4.04 (3.04,5.04)	0.9925
P2S	5.24 (4.93,5.56)	5.21 (4.84,5.59)	5.52 (4.70,6.34)	0.4873
P3	3.02 (2.72,3.33)	2.89 (2.53,3.26)	3.88 (3.02,4.74)	0.0253
P4	5.23 (4.87,5.60)	5.35 (4.90,5.79)	5.04 (4.08,6.00)	0.5634
P5	6.86 (6.56,7.16)	6.79 (6.43,7.15)	6.92 (6.12,7.72)	0.7568
P6H	4.90 (4.55,5.25)	4.88 (4.49,5.28)	5.00 (3.92,6.08)	0.8159
P6S	6.50 (6.15,6.85)	6.73 (6.34,7.13)	5.52 (4.42,6.62)	0.0144
P7	6.65 (6.29,7.01)	6.58 (6.15,7.02)	6.80 (5.80,7.80)	0.6775
Rank				
1	P1	P1	P1	
2	P3	P3	P3	
3	P2H	P2H	P2H	
4	P6H	P6H	P6H	
5	P4	P4	P4	
6	P2S	P2S	P2S	
7	P6S	P6S	P6S	
8	P7	P7	P7	
9	P5	P5	P5	

3.3 Affective Domain

Table 4 showcases the average values and rankings for the affective domain. Across the international and European groups much commonality is shown, noting that the first three items for the Europe group have the same average. The Australasia group differs substantially for this domain. It is of substantial interest to understand why such a large variation occurs. Such differences are not surprising though, during the authors submission of previous papers involving LLOM, the greatest reviewer debate has been on the affective items. Could it be that differences in culture are most present in this domain due to the focus of less technical items? With the larger Australian sample, a future study will need to look at the differences across Australian institutions. Should alignment occur across the affective domain in Australia, this would create an interesting research pathway to investigate further.

It can be observed that (A1) '*work in a team to conduct experiments, diagnose problems and analyse results*' is deemed most important, not surprisingly as much work and focus in recent years has been placed on teamwork throughout the world [9, 10]. All groups placed 'C*onsider ethical issues in laboratory experimentation and communication of discoveries*' (A7) as least important. With ethical laboratory practises uniformly positioned last, this can be concerning, and it does suggest engineers need greater reflection on affective skill development. Is it wise for engineers not to value ethical practice as highly important? What negative consequences can result on the engineering profession if data collection and communication is not been completed ethically? As is implied by Gwynne-Evans, Chetty [11], does ethics need repositioning?

Table 4. Learning Objectives Affective Domain (Averages With 95% Confidence Interval) And Ranking Order

Obj.	International	Australasia	Europe	ANOVA
A1	2.49 (2.21,2.77)	3.00 (3.00,3.00)	3.00 (1.15,4.85)	0.514
A2	3.24 (3.01,3.47)	4.50 (1.85,10.85)	3.00 (1.69,4.31)	0.2264
A3	3.58 (3.27,3.88)	2.50 (16.56,21.56)	3.00 (1.23,4.77)	0.5492
A4	5.50 (5.28,5.72)	6.00 (6.71,18.71)	6.14 (5.31,6.97)	0.3953
A5	4.44 (4.13,4.76)	3.50 (28.27,35.27)	3.43 (1.17,5.68)	0.8773
A6	4.23 (3.97,4.49)	4.50 (27.27,36.27)	4.57 (2.90,6.25)	0.0556
A7	4.53 (4.20,4.85)	4.00 (21.41,29.41)	4.86 (3.40,6.31)	0.7761
Rank				
1	A1	A3	A1	
2	A2	A1	A2	
3	A3	A5	A3	
4	A6	A7	A5	
5	A5	A2	A6	
6	A7	A6	A7	
7	A4	A4	A4	

4 SUMMARY

Regarding the research question, *how do Australasian and European academics rank laboratory objectives compared to the international community*, this work has found that substantial commonality exists across the cognitive and psychomotor domains. The greatest differences occur in the affective domain. This is not surprising given the attention to cognitive learning and somewhat psychomotor learning found through assessment [4]. Further research will need to investigate why the greatest differences occurred across the affective items. Do the non-technical items integrate with cultural expectations and differences? With topics such as emotional intelligence largely missing from the engineering curriculum, but highly sought after in the workplace [12], it appears greater research, discussion and reflection on the affective items is needed by the engineering academic community. Future work will look at comparisons across disciplines and laboratory modes.

ACKNOWLEDGMENT

This study is an initiative of the Early Career Academy of the Australasian Association of Engineering Education. Funding support to attend the conference was provided by a RevITAlising Research Grant (RITA) 2021

REFERENCES

[1] Garcia-Loro, F., et al. *Laboratories 4.0: Laboratories for Emerging Demands under Industry 4.0 Paradigm*. in *2021 IEEE Global Engineering Education Conference (EDUCON)*. 2021.

[2] Ergüzen, A., et al., *Improving Technological Infrastructure of Distance Education through Trustworthy Platform-Independent Virtual Software Application Pools.* Applied Sciences, 2021. **11**(3): p. 1214.

[3] Brinson, J.R., *Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research.* Computers & Education, 2015. **87**: p. 218-237.

[4] Nikolic, S., et al., *Remote, Simulation or Traditional Engineering Teaching Laboratory: A Systematic Literature Review of Assessment Implementations to Measure Student Achievement or Learning.* European Journal of Engineering Education, 2021. **46**(6): p. 1141-1162.

[5] Wijenayake, C., et al. *Managing Hands-on Electrical and Computer Engineering Labs during the COVID-19 Pandemic*. in *2021 IEEE International Conference on Engineering, Technology & Education (TALE)*. 2021.

[6] Feisel, L., et al. *Learning objectives for engineering education laboratories*. in *Frontiers in Education, 2002. FIE 2002. 32nd Annual*. 2002.

[7] Nikolic, S., et al., *Laboratory Learning Objectives Measurement: Relationships Between Student Evaluation Scores and Perceived Learning.* IEEE Transactions on Education, 2021. **64**(2): p. 163-171.

[8] Nikolic, S., et al., *Decoding Student Satisfaction: How to Manage and Improve the Laboratory Experience.* IEEE Transactions on Education, 2015. **58**(3): p. 151-158.

[9] Avila, D.T., W. Van Petegem, and A. Libotton, *ASEST framework: a proposal for improving teamwork by making cohesive software engineering student teams.* European Journal of Engineering Education, 2021. **46**(5): p. 750-764.

[10] Gregory, S., et al. *New applications, new global audiences: Educators repurposing and reusing 3D virtual and immersive learning resources*. in *Australasian Society for Computers in Learning and Tertiary Education (ascilite)*. 2015. Australasian Society for Computers in Learning in Tertiary Education.

[11] Gwynne-Evans, A.J., M. Chetty, and S. Junaid, *Repositioning ethics at the heart of engineering graduate attributes.* Australasian Journal of Engineering Education, 2021. **26**(1): p. 7-24.

[12] Cerri, S.T., *The Fully Integrated Engineer: Combining Technical Ability and Leadership Prowess*. 1 ed. IEEE PCS Professional Engineering Communication Series. 2016, New York: Wiley.