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An Australian University Comparison of Engineering Laboratory Learning Objectives Rankings

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ABSTRACT

CONTEXT

The laboratory plays an important role within engineering education. Systematic literature reviews suggest the major focus of laboratory research is on the cognitive domain or that learning objectives are not clearly articulated. Work is needed to better understand holistic learning.

PURPOSE OR GOAL

This study builds upon previous research to develop a holistic understanding of laboratory learning in engineering. This study scaffolds previous research by exploring the importance of a holistic list of learning objectives. It further develops an understanding of what factors may influence ranking decisions.

APPROACH OR METHODOLOGY/METHODS

Australian academics were requested to rank items from the Laboratory Learning Objectives Measurement (LLOM) instrument using a Qualtrics survey. The items are separated across the cognitive, psychomotor and affective learning domains. A total of 95 academics from Australian institutions completed the survey.

ACTUAL OR ANTICIPATED OUTCOMES

While a general structure of alignment was found across the learning objectives across the three domains, the alignment was strongest across the affective domain. Evidence suggests that engineering discipline based decisions influence ranking order in the cognitive and psychomotor domains.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The most important and least important objectives for each domain were found and was mostly consistent across Australian institutions. For everything in between (cognitive and psychomotor domains), further research is required to understand the impacts of discipline influences on ranking order. While previous research shows that affective items differ across international borders, they appeared uniform within Australian borders. This suggests that local culture, accreditation or expectations influence the importance of non-technical items and requires further exploration.

KEYWORDS

Assessment, Blooms Taxonomy, Laboratory, Learning Objectives

Introduction

The laboratory plays an important role in providing students a diverse range of skills and learning experiences to prepare them for their engineering careers (Al-Ataby & Al-Nuaimy, 2019; Kočović, Luković, Živković, & Šimunović, 2022). However, systematic literature reviews (Brinson, 2015; Sasha Nikolic, Ros, Jovanovic, & Stanisavljevic, 2021) suggest that most of the laboratory assessment and research focus is on cognitive learning outcomes. While it is well recognised that the learning objectives in the laboratory is diverse (Feisel et al., 2002), academic approaches to assessing learning in the laboratory is limited. Research suggests that there is still much to explore and understand in terms of our how we can maximise learning through assessment (Griffith, Rosen, Byrnes, Blake, & Spencer, 2020). Before we can improve our understanding of laboratory assessment, we first need to gain a better understanding of which learning objectives are most important. If we know what is important, we can develop an instrument to confirm if those objectives are in fact being appropriately assessed.

The importance of this work has been further increased and highlighted by the impacts of COVID19. Universities were required to quickly change learning modes (Wijenayake et al., 2021). Laboratories were particularly hit hard with many traditional face-to-face classes shifting rapidly to recorded or online only formats. By understanding laboratory learning objectives more holistically, the community can more easily measure the strengths and weaknesses of such changes.

This works scaffolds upon the authors previous work to determine a ranking order of laboratory learning objectives, and more importantly determine what influences their importance. The laboratory objectives were separated across the cognitive, psychomotor and affective domains. The learning domains are explained in more detail in the following section. An earlier study (Sasha. Nikolic et al., 2022) compared the ranking responses from engineering academics across international, European and Australasian groupings. The study found that across the cognitive and psychomotor domains there was much similarity in rankings. However, much divergence was discovered in the affective domain. The research suggested that local factors may influence some of the affective ranking decisions. To explore this hypothesis further it was important to examine ranking at a local level. Therefore, this study will explore the dataset further, by concentrating the analysis on local Australian institutions. That is, the study seeks to answer the research question *are there differences in the way Australian academics rank laboratory learning objectives?*

The LLOM Instrument

Learning in the laboratory can be connected across the cognitive, psychomotor and affective domains (S. Nikolic, Suesse, Jovanovic, & Stanisavljevic, 2021). 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). Previous research using assessment data suggests that laboratory achievement occurs across more than one domain (Sasha Nikolic, Suesse, Goldfinch, & McCarthy, 2015), supporting such notions. The LLOM instrument combines the 13 objectives listed in (Feisel et al., 2002) with the three Blooms Taxonomy level descriptors to provide a holistic list as provided in Table 1. Applying the learning process derived from Blooms Taxonomy is common (Saha, 2022), but usually only concentrated on the cognitive domain.

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 and use *tools* 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

Methodology

Through an initiative of the Australasian Association of Engineering Education, 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 S. Nikolic et al. (2021). 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, 95 of the completed responses came from Australian universities. This study provides an analysis of the Australian responses only. Responses were received from eleven different Australian universities. The largest responses from the university in each state was explored separately, UNSW (22), USC (11), UTAS (9) and UWA (12). Responses from nine other university were grouped under 'other' (41).

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 four groups as outlined in the previous section. 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 0.4372, Table 3 is 0.5026 and for Table 4 is 0.03242. 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.

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 a somewhat general trend in ranking order. The three most important items are generally at the top and the three least important items towards the bottom. The items ranked in the middle vary the most across disciplines. Responses from the UWA demonstrate the greatest differences in ranking order. UNSW and USC also demonstrate some noticeable differences, including statistically significant differences in the weighting of some items. This data is in contrast to the authors earlier study (Sasha. Nikolic et al., 2022) that found much higher levels of similarity across international locations.

To determine why such variability existed across the three universities the disciplines associated with the responses were examined. Responses from UNSW were most influenced from aeronautical, biomedical and chemical engineering. USC responses were most influenced from mechanical, biomedical and mechatronics engineering. While UWA responses were most influenced from software, computer and materials engineering. Therefore, it appears that differences in ranking order are less influenced by location, and more influenced by the discipline of the survey participant. This requires further investigation in a new study investigating the differences across engineering disciplines.

Across the universities C1 (understanding) and C2 (design) were deemed to be the most important objectives. The least important item is C9 (laboratory-based writing). Interestingly, while lab reports and writing are deemed as least important, the work by Sasha Nikolic et al. (2021) found that they were one of the most used assessment types. It would be interesting for a follow up investigation to determine why laboratory report writing is so heavily used in assessments but considered such a low ranked skill for students to obtain.

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

Obj.	Collectively	Other	UNSW	USC	UTAS	UWA	ANOVA
C1	3.09 (2.68,3.51)	2.85 (2.23,3.48)	3.18 (2.28,4.09)	3.27 (1.57,4.97)	3.22 (1.80,4.65)	3.50 (2.27,4.73)	0.878
C2	3.17 (2.69,3.64)	3.27 (2.46,4.08)	3.68 (2.50,4.86)	1.91 (1.27,2.54)	3.11 (1.46,4.76)	3.08 (2.05,4.11)	0.363
C3	4.24 (3.73,4.76)	3.88 (3.16,4.59)	5.00 (3.81,6.19)	4.45 (2.30,6.61)	5.11 (3.42,6.81)	3.25 (1.67,4.83)	0.216
C4	5.39 (4.92,5.86)	5.22 (4.47,5.97)	5.86 (4.93,6.79)	6.00 (4.59,7.41)	5.78 (4.07,7.49)	4.25 (2.74,5.76)	0.271
C5	4.83 (4.49,5.17)	5.05 (4.55,5.54)	4.27 (3.51,5.04)	4.18 (3.29,5.07)	5.22 (3.70,6.75)	5.42 (4.39,6.45)	0.138
C6	6.49 (6.03,6.96)	6.71 (6.01,7.40)	6.50 (5.45,7.55)	6.09 (4.64,7.55)	5.33 (3.06,7.61)	7.00 (5.85,8.15)	0.46
C7	3.86 (3.43,4.30)	3.98 (3.30,4.65)	3.00 (2.25,3.75)	4.73 (3.68,5.77)	4.00 (1.89,6.11)	4.17 (2.50,5.83)	0.214
C8	6.60 (6.20,7.00)	6.63 (6.03,7.24)	6.05 (5.23,6.86)	7.09 (6.22,7.96)	6.44 (4.37,8.52)	7.17 (5.82,8.52)	0.475
C9	7.32 (6.92,7.72)	7.41 (6.89,7.94)	7.45 (6.51,8.40)	7.27 (5.68,8.87)	6.78 (4.79,8.77)	7.17 (5.90,8.43)	0.919
Rank							
1	C1	C1	C1	C2	C2	C2	
2	C2	C2	C7	C1	C1	C3	
3	C7	C3	C2	C5	C7	C1	
4	C3	C7	C5	C3	C3	C7	
5	C5	C5	C3	C7	C5	C4	
6	C4	C4	C4	C4	C6	C5	
7	C6	C8	C8	C6	C4	C6	
8	C8	C6	C6	C8	C8	C8	
9	C9	C9	C9	C9	C9	C9	

Psychomotor Domain

Table 3 showcases the average values and rankings for the psychomotor domain. As per the cognitive domain, it can be seen that across the three comparison groups there is a somewhat general trend in ranking order. The three most important items are generally at the top, the three least important items towards the bottom, and the items ranked in the middle found around the middle. P6H (operate instruments) was one of the items that varied the most in ranking order across the disciplines. As before, looking at the data behind the groupings, the disciplines behind the respondents appear to be the influencing factor behind ranking order. For example, P6H might be much lower at UWA because of the larger percentage of responses from software engineers. This confirms the need for further investigation on ranking order in relation to engineering discipline.

P1 (correctness) and P3 (execution) are ranked as most important. This is expected as we want students to correctly conduct activities in a laboratory activity. P5 (using psychomotor skills for faultfinding) was mostly deemed as least important. This is deemed interesting, as again previous research (Sasha Nikolic, Ritz, Vial, Ros, & Stirling, 2015) has highlighted the importance of fault finding in laboratory success and satisfaction.

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

Obj.	Collectively	Other	UNSW	USC	UTAS	UWA	ANOVA
P1	2.63 (2.24,3.02)	2.83 (2.19,3.47)	3.00 (2.07,3.93)	2.18 (0.99,3.38)	1.89 (0.91,2.86)	2.25 (1.13,3.37)	0.4651
P2H	4.07 (3.63,4.51)	3.49 (2.86,4.11)	4.91 (4.20,5.62)	4.18 (2.29,6.08)	4.00 (2.42,5.58)	4.50 (2.75,6.25)	0.1442
P2S	5.13 (4.72,5.53)	4.90 (4.21,5.60)	5.55 (4.82,6.27)	4.64 (3.50,5.77)	5.67 (4.18,7.16)	5.17 (3.74,6.60)	0.5979
P3	2.73 (2.35,3.10)	2.80 (2.22,3.39)	2.50 (1.63,3.37)	2.73 (1.35,4.11)	2.67 (1.34,4.00)	2.92 (1.92,3.91)	0.9696
P4	5.24 (4.76,5.72)	5.12 (4.36,5.88)	5.68 (4.47,6.89)	6.00 (4.88,7.12)	4.78 (3.20,6.35)	4.50 (3.13,5.87)	0.4769
P5	6.89 (6.51,7.28)	6.80 (6.24,7.37)	7.00 (6.03,7.97)	6.64 (4.88,8.40)	6.89 (5.71,8.07)	7.25 (6.27,8.23)	0.9447
P6H	4.89 (4.46,5.32)	5.02 (4.35,5.70)	3.91 (3.07,4.75)	5.45 (4.32,6.59)	5.00 (3.28,6.72)	5.67 (4.17,7.16)	0.1158
P6S	6.73 (6.29,7.17)	7.34 (6.83,7.85)	5.95 (4.80,7.11)	6.55 (5.03,8.06)	7.56 (6.11,9.00)	5.58 (4.06,7.10)	0.0249
P7	6.68 (6.22,7.15)	6.68 (5.97,7.39)	6.50 (5.37,7.63)	6.64 (5.13,8.15)	6.56 (4.52,8.59)	7.17 (5.90,8.43)	0.9527
Rank							
1	P1	P3	P3	P1	P1	P1	
2	P3	P1	P1	P3	P3	P3	
3	P2H	P2H	P6H	P2H	P2H	P2H	
4	P6H	P2S	P2H	P2S	P4	P4	
5	P2S	P6H	P2S	P6H	P6H	P2S	
6	P4	P4	P4	P4	P2S	P6S	
7	P7	P7	P6S	P6S	P7	P6H	
8	P6S	P5	P7	P7	P5	P7	
9	P5	P6S	P5	P5	P6S	P5	

Affective Domain

Table 4 showcases the average values and rankings for the affective domain. The data shows that apart from UWA, most of the universities are in alignment with ranking order. This is in contrast to the authors earlier work based on location (Sasha. Nikolic et al., 2022) that found across international borders the cognitive and psychomotor domains were well aligned, but the affective had substantial differences. This may suggest that local factors may be an important influencer. This may come from accreditation and or general country/continent-based life perspectives. This is something beyond this paper and deserves a follow up investigation. The UWA difference, may again be related to the software/computer engineering focus of responders, highlighting a discipline difference from other engineering disciplines that needs further investigation.

Across the universities A1 (teamwork) was deemed as most important. This is not surprising due to the emphasis of teamwork in Engineers Australia and the growing research (Trevelyan, 2014) that highlights its importance to the engineering profession. Deemed least important was A4 (ethics). This is somewhat surprising. Is it wise for engineers not to value ethical practice as highly important? Is it possible that engineering academics are not sure about how ethics can be applied in the laboratory? For example, do they consider what negative consequences can result on the engineering profession if data collection and communication is not completed ethically? As is implied by Gwynne-Evans, Chetty, and Junaid (2021), does ethics need repositioning?

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

Obj.	Collectively	Other	UNSW	USC	UTAS	UWA	ANOVA
A1	2.64 (2.24,3.04)	2.37 (1.71,3.02)	2.64 (1.89,3.38)	2.27 (1.07,3.48)	3.89 (2.38,5.40)	3.00 (1.67,4.33)	0.26587
A2	3.16 (2.86,3.46)	2.98 (2.58,3.37)	3.09 (2.44,3.75)	3.09 (2.33,3.85)	2.44 (1.35,3.54)	4.50 (3.33,5.67)	0.00957
A3	3.22 (2.84,3.60)	2.93 (2.41,3.45)	3.32 (2.44,4.20)	3.27 (1.99,4.55)	3.56 (2.01,5.10)	3.75 (2.37,5.13)	0.67259
A4	5.44 (5.17,5.71)	5.34 (4.91,5.77)	5.55 (5.00,6.09)	5.64 (5.09,6.18)	5.22 (3.70,6.75)	5.58 (4.75,6.42)	0.91373
A5	4.52 (4.10,4.93)	5.10 (4.60,5.60)	3.86 (2.78,4.94)	4.45 (2.91,6.00)	4.78 (3.20,6.35)	3.58 (2.19,4.98)	0.0841
A6	4.48 (4.15,4.82)	4.59 (4.04,5.13)	4.50 (3.82,5.18)	4.27 (3.03,5.51)	4.11 (2.76,5.47)	4.58 (3.71,5.46)	0.93336
A7	4.54 (4.12,4.95)	4.71 (4.08,5.33)	5.05 (4.23,5.86)	5.00 (3.62,6.38)	4.00 (2.28,5.72)	3.00 (1.76,4.24)	0.04305
Rank							
1	A1	A1	A1	A1	A2	A1	
2	A2	A3	A2	A2	A3	A7	
3	A3	A2	A3	A3	A1	A5	
4	A6	A6	A5	A6	A7	A3	
5	A5	A7	A6	A5	A6	A2	
6	A7	A5	A7	A7	A5	A6	
7	A4	A4	A4	A4	A4	A4	

Summary

Regarding the research question, *are there differences in the way Australian academics rank laboratory learning objectives*, this work has found that some commonality exists across the cognitive and psychomotor domains, but much greater alignment across the affective domain. The differences in the cognitive and psychomotor domain suggest that there are definitely other factors in play. This is supported by the authors previous research (Sasha. Nikolic et al., 2022) that found substantial alignment across the two domains when comparing international locations. The most obvious difference in the dataset is the percentage of respondents being associated with different engineering backgrounds. This requires a separate study on its own to clarify. However, at face value it appears that discipline has a greater influence then the university staff are located at.

The affective domain was of greatest interest in that the data showed the most ranking alignment across institutions. This was in contrast to the previous study that showed much misalignment when comparing the affective domain across international locations. The data from the two studies suggest that disciplines influence ranking in the cognitive and psychomotor domains, and local perspectives influence the affective domain. Future research will work to clarify such observations.

The findings from this body of work will help researchers better understand what objectives are important, which can be ultimately used to improve laboratory experiences. An improved laboratory experiences comes about from improvements in experimentation, facilities and teaching quality (S. Nikolic et al., 2021; Sasha Nikolic, Suesse, McCarthy, & Goldfinch, 2017).

It must be repeated that the three learning domains are not separate and that domain overlap occurs across the items as listed. Findings are limited by the size of the sample and the diversity in responses.

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