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Evaluating program learning outcomes using a student perspective and systems engineering lens

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ABSTRACT

CONTEXT

A systems engineering approach involves ensuring that the outputs of a system are as expected through a process of verification and validation against design requirements at various levels. In an education setting, requirements are often expressed as course learning outcomes, achieved through a series of learning activities, and verified and validated against assessment items. These course learning outcomes are necessarily abstracted somewhat imperfectly to program learning outcomes (PLOs). However, in the education setting, there is often no holistic assessment of the overall program learning outcomes. In contrast, a systems engineering approach requires verification and validation at the subsystem and whole-of-system level.

PURPOSE OR GOAL

A fundamental concept in systems engineering is that a system is greater than the sum of its component parts. This paper explores the extent to which students perceive the relationship between learning experiences and PLOs in the formal curriculum, and what other factors students consider are instrumental in achieving PLOs. By identifying how students believe that they achieve PLOs, we can better understand and support areas of learning not captured in the formal curriculum.

APPROACH OR METHODOLOGY/METHODS

Interviews were held with 17 final-year engineering students around their perceptions of PLOs achieved throughout their degree. Participants were given a series of activities aimed at understanding the extent to which students believe PLOs were achieved within the formal curriculum and were invited into open-ended discussions based their responses. Responses were analysed post-interview for common themes and response patterns.

ACTUAL OR ANTICIPATED OUTCOMES

The data collected through this project suggests that participants achieve a baseline level of PLOs through contexts in formal curriculum. However, it was common to observe that PLOs based on professional and personal attributes are more likely to be attributed to learning contexts outside of the formal curriculum. This observation presents an opportunity to explore how universities can best support students engaging in PLOs in broad contexts.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

In this case study, we found that students believe that PLOs could be achieved through formal curriculum, demonstrating that students can reconcile the relationship between the two. However, a whole-of-system view of how students perceive they achieve PLOs has identified potential areas that could be enhanced outside of coursework, such as developing professional attributes.

KEYWORDS

Program learning outcomes; Systems engineering; Verification and validation; Test and evaluation.

Background

Constructive alignment is an approach that can be used by education systems for ensuring students meet the learning outcomes at the various levels of education through stating the curriculum in the form of clear objectives, and then teaching methods and tasks are developed to achieve the objectives (Gilic et al., 2022; Ruge et al., 2019). The various levels can be expressed through programs, courses, and tasks where a program is the overall activities that make up the degree that the students enrol in to gain that qualification, a course is the class that the student enrols in, and a task is an artefact or assessment that is completed within a course. Constructive alignment relies on cohesive connections between the various levels, and draws parallels to how systems engineering describes relationships between elements in a system.

Systems can be described with three parts: the elements, the relationships and/or interactions, and the whole; the three parts form the basis of systems theory (Adams et al., 2014; Faulconbridge & Dowling, 2010). Systems theory considers the whole, which is made up of many elements which have interactions and/or relationships with other elements, while maintaining a view of the system holistically (Ljungblom & Lennerfors, 2021; Pouvreau, 2014). Systems engineering then provides a framework for complicated systems to be analysed, tested, and evaluated. Testing and evaluating is a useful process in systems engineering as it is commonly used to check that the system is internally consistent. This includes validating the system's output to the desired goal and verifying that the elements of the system map to the whole as intended.

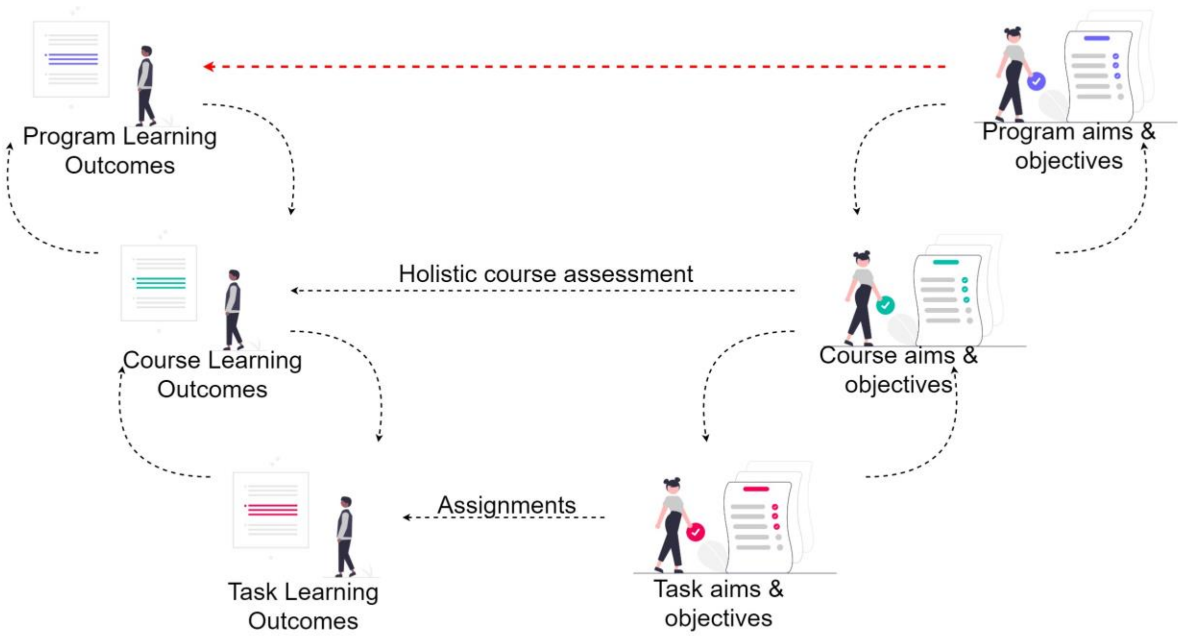

Figure 1: V-model of the engineering education structure of LOs and associated aims and objectives (Chinn & Browne, 2023)

A representation of an engineering education system that uses constructive alignment with a systems engineering lens shown in Figure 1 in the form a V-model. The V-model is a systems development life cycle model applicable to a wide variety of systems beyond engineering education such as information technology systems, control systems, and consumer products (INCOSE, 2023; ISO/IEC/IEEE, 2018). The elements on the left of Figure 1 are the plans or intended outcomes: the program learning outcomes (PLOs) are the goals of the program, the course learning outcomes are the goals of the courses that make up the program, and the task learning outcomes are the goals of the tasks that are assigned within a course. The level of abstraction between the learning outcomes and the associated aims and objectives varies and the mapping is tested at varying rigor; this is represented through dotted lines between the elements.

In any education system, learning involves both formal and informal learning. Johnson and Majewska describe informal learning as learning outside of the systematic process/structure of formal education (Johnson & Majewska, 2022). Elements of curriculum can be achieved within informal learning, not just formal learning, and perceptions of where students acquire this learning can be based on a number of factors. Given the boundary between informal and formal learning is fuzzy, there is an opportunity to understand where students perceive they are acquiring the skills described in learning outcomes.

In the context of this study, the relevant PLOs are listed in Table 1. These PLOs have been given a simple reference name and have been categorised into a broad EA Stage 1 Competency by the researchers (*Stage 1 Competency Standard for Professional Engineers | Engineers Australia*, 2022).

Table 1: List of PLOs from the engineering program case study.

PLO	Description	Broad EA Stage 1 Competency
PLO1 Methods	Professionally apply systematic engineering methods to design optimised and sustainable solutions to complex, multi-disciplinary real-world engineering problems.	Engineering Application Ability
PLO2 Theory	Formulate and evaluate solutions to engineering problems by selecting and applying theoretical principles and methods from the underpinning physical, mathematical and information sciences	Knowledge and Skill Base
PLO3 Specialisation	Proficiently apply advanced technical knowledge and appropriate tools in at least one field of engineering specialisation	Engineering Application Ability
PLO4 Trends	Identify and critically evaluate current developments and emerging trends within at least one field of engineering specialisation	Knowledge and Skill Base
PLO5 Practice	Understand the contextual factors that influence professional engineering practice, and identify the potential societal, ethical, and environmental impact of engineering activities	Knowledge and Skill Base
PLO6 Communication	Communicate effectively with colleagues, other engineering professionals and the broader community employing a range of communication media and tools	Professional and Personal Attributes
PLO7 Research	Engage in independent research and investigation through the application of research-based knowledge and research methods, including searching, analysing, and evaluating information sources within and beyond their engineering discipline	Knowledge and Skill Base
PLO8 Reflection	Engage effectively in critical reflection and independent learning to continue practicing at the forefront of the discipline	Professional and Personal Attributes
PLO9 Teamwork	Work effectively and proactively within cross-cultural, multi-disciplinary teams, demonstrating autonomy, ethical conduct, well-developed judgement, adaptability, and responsibility to achieve engineering outcomes at a high standard	Professional and Personal Attributes

This paper explores the relationship between PLOs and the students' perceived experience of engaging with the PLOs, and what factors they believe affects their ability to achieve the PLOs. It is hypothesized that the students perceive the PLOs differently through a mix of formal and informal learning experiences. Through investigating how students perceive PLO achievement, there is better understanding on the students' sentiment around informal learning and understanding the student's perception on the implementation of constructive alignment.

Methodology

To investigate students' perception, a 15-minute interview protocol and survey was conducted. The survey was advertised to undergraduate engineering students completing an engineering degree at the Australian National University. Students were required to have completed 3 years of study or have graduated with their degree within the last year. The interviews were held online to ensure that the sample cohort could include remote students. The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (Protocol 2022/475).

Interviews were held online, and consisted of a survey with two questions which reflect where the students are learning the PLOs and whether they are achieving them.

In the first question, the participants were given a matrix table that contained various learning environments, summarised in Table 2 (see Results), and were asked to select the environment that contributed the most to the achievement of the PLOs. The matrix also includes the option of 'Other' as it was possible that the listed environments do not match the participant's environment, or the participant may not identify they achieved the listed PLO. The 'Other' option involves an open-ended response where the participant could provide further details. Overall, this question addresses where the students perceive the PLOs.

The second question followed-on from answers in the first question given by the participants. The participants were asked to grade each PLO on a scale of 'Definitely Yes' to 'Definitely No' on whether there was an opportunity to achieve the PLO through the formal curriculum. This question provides validation on whether students perceive the PLOs was achievable within the engineering program.

Both questions on the survey were prompts for optional free-text responses. After completion, participants were sent a link to review and confirm responses. This was to ensure that the participants could verify that their answers were captured correctly and provide the opportunity to change their answers or withdraw from the study. The review and withdraw period were seven days from the survey; afterwards, the participants could no longer withdraw from the study. After the seven-day withdrawal period, the data collected were included in the dataset for processing and analysis.

Results

17 students participated in the protocol and completed the survey. A count and percentage of responses are shown in Table 2 for the perceived learning environment and whether the PLO was perceived as achievable for each PLO.

PLO1 (Methods), PLO2 (Theory), PLO3 (Specialisation), PLO5 (Practice), PLO7 (Research) and PLO8 (Reflection) were most clearly associated with an Engineering Course learning environment, accounting for 53% of responses or greater. PLO4 (Trends), PLO6 (Communication) and PLO9 (Teamwork) were more varied, with results spread between Engineering Course, Extra-curricular, Work Experience/Internship, and Paid Work learning environments.

PLO1 (Methods), PLO2 (Theory), PLO3 (Specialisation), and PLO7 (Research) were most clearly perceived as achievable within the formal curriculum, with PLO4 (Trends), PLO5 (Practice), PLO6 (Communication), PLO8 (Reflection) and PLO9 (Teamwork) showing a mix of results.

Table 2: Count and percentages of results by program learning outcome (n=17)

	PLO1 Methods	**PLO2** Theory	**PLO3** Special'n	**PLO4** Trends	**PLO5** Practice	**PLO6** Comm'n	**PLO7** Research	**PLO8** Reflection	**PLO9** Teamwork
Perceived Learning Environment									
Engineering Course	10 (59%)	13 (76%)	11 (65%)	5 (29%)	11 (65%)	5 (29%)	9 (53%)	9 (53%)	6 (35%)
Any Course	-	1 (6%)	2 (12%)	-	-	-	-	1 (6%)	-
External Course	-	-	-	-	-	-	1 (6%)	-	-
Extra-Curricular	-	-	1 (6%)	3 (18%)	1 (6%)	1 (6%)	2 (12%)	3 (18%)	2 (12%)
Work Experience /Internship	3 (18%)	1 (6%)	1 (6%)	1 (6%)	2 (12%)	5 (29%)	1 (6%)	1 (6%)	3 (18%)
Paid Work	1 (6%)	-	1 (6%)	4 (24%)	1 (6%)	5 (29%)	2 (12%)	1 (6%)	6 (35%)
Other	3 (18%)	2 (12%)	1 (6%)	4 (24%)	2 (12%)	1 (6%)	2 (12%)	2 (12%)	-
Perceived as Achievable in Formal Curriculum									
Definitely Yes	7 (41%)	7 (41%)	6 (35%)	1 (6%)	3 (18%)	4 (24%)	7 (41%)	3 (18%)	2 (12%)
Yes	7 (41%)	7 (41%)	8 (47%)	2 (12%)	7 (41%)	3 (18%)	6 (35%)	4 (24%)	6 (35%)
Somewhat	3 (18%)	2 (12%)	2 (12%)	9 (53%)	6 (35%)	4 (24%)	4 (24%)	5 (29%)	8 (47%)
No	-	1 (6%)	1 (6%)	4 (24%)	1 (6%)	4 (24%)	-	5 (29%)	-
Definitely No	-	-	-	1 (6%)	-	2 (12%)	-	-	1 (6%)

Note: Column percentages may not equal 100% due to rounding.

The learning environments in Table 2 have been categorised further into Internal contexts (Engineering Course, Any Course and External Course), External contexts (Extra-curricular, Work Experience, Internship and Paid Work) and Undefined (Other) in Table 3. This further emphasises the observations in Table 2, where Internal learning environments are most strongly associated with PLO1 (Methods), PLO2 (Theory), PLO3 (Specialisation), PLO5 (Practice), PLO7 (Research) and PLO8 (Reflection), and PLO4 (Trends), PLO6 (Communication) and PLO9 (Teamwork) more commonly associated with External learning environments. In summary, Table 2 presents that three PLOs are more commonly associated with learning in external contexts, and six PLOs are associated with internal contexts.

Table 3: Count and percentages of learning contexts by program learning outcome (n=17)

	PLO1 Methods	**PLO2** Theory	**PLO3** Special'n	**PLO4** Trends	**PLO5** Practice	**PLO6** Comm'n	**PLO7** Research	**PLO8** Reflection	**PLO9** Teamwork
Perceived Learning Environment									
Internal contexts	10 (59%)	14 (82%)	13 (76%)	5 (29%)	11 (65%)	5 (29%)	10 (58%)	10 (58%)	6 (35%)
External contexts	4 (24%)	1 (6%)	3 (18%)	8 (47%)	4 (24%)	11 (65%)	5 (29%)	5 (29%)	11 (65%)
Undefined	3 (18%)	2 (12%)	1 (6%)	4 (24%)	2 (12%)	1 (6%)	2 (12%)	2 (12%)	-

Further, the PLOs have been categorised in Table 4 according to the broad Engineers Australia Stage 1 Competency grouping shown in Table 1. This shows that students perceive that they are more likely location to associate technical PLOs, such as those represented in Knowledge and Skill Base and Engineering Application Ability, in internal learning contexts, Whereas Professional and Personal Attributes are associated first with external learning contexts, then with internal learning contexts.

Table 4: Percentage of responses with learning outcomes my EA Stage 1 Competencies

	Knowledge and Skill Base	Engineering Application Ability	Professional and Personal Attributes
Perceived Learning Environment			
Internal contexts	58.9%	67.7%	41.2%
External contexts	26.5%	20.7%	52.9%
Undefined	14.7%	11.8%	5.9%

The free text responses were briefly analysed by theme to illustrate the perspectives of the participants. Notable themes are presented in Table 5, with an indication of frequency and an illustrative quotation from a respondent in that category. These quotations provide an insight into student sentiment on the delivery of the PLOs and include awareness of confounding factors such as degree differences, individual mindsets, and learning environment expectations.

Table 5: Common themes from the free-text response associated with the PLO types.

EA Stage 1 Competency	Theme	Freq.	Illustrative Quotes from Respondents
Knowledge and Skill Base	Degree differences	2	*R&D course in particular had many opportunities for L07, was a focus for the degree.*
	Learning new technologies	3	*…may just be a lack of communication from lecturers as to what is current or older information.*
Engineering Application Ability	Teaching quality	4	*…engineering at ANU has provided me with what to do, but not effectively helped me in how to learn these things or how to do them*
	Workplace preference	2	*…the "professional" component (of PLO1) being something I feel is better learnt in workplace than with peers of varying degrees of professionalism…*
Professional and Personal Attributes	Mark motivation dynamics	2	*…I don't think the ANU has a perfect system for accountability in teamwork projects, particularly when taking into account that different students are "mark-motivated" to varying degrees…*

Discussion

This study explored how a small cohort of students in the engineering discipline interact with the broader learning environment to achieve program learning objectives. To preface the discussion, some of the key limitations need to be addressed.

The small participant cohort size, and methodology of recruitment through university platforms, social media, and word-of-mouth, may not be representative of the entire cohort. A broader study with a representative cohort may identify different trends. The cohort was drawn from a single discipline in a single university, so further work either in other disciplines or at other institutions is required to explore whether these trends are endemic to engineering education or are an indication of learning environment at other institutions. Further, the sample cohort was drawn from students towards the completion of their degree: a cohort more likely to have recent proximity to experiences outside of the formal curriculum, such as work experience or paid work. Further work is required to understand whether students earlier in their programs would have similar experiences. Lastly, the results collected represent of a subjective perception of experience, and further work could be done to explore how students achieve learning outcomes through a more objective test against PLOs.

Despite maintaining constructive alignment within the curriculum, a key indication from the results suggest that students perceive that they achieve PLOs in multiple environments outside of formal education (Table 2). This suggests that there is more to an engineering degree than simply the component parts combining into a whole as intended. Furthermore, the results suggest there is value in testing and evaluating the component parts and the whole to understand how students interact with an engineering degree.

In this study, participants identified that it was possible to achieve all program learning outcomes through formal curriculum (Table 2). However, participants were more likely to associate learning outcomes relating to professional and personal skills (PLO6, PLO9) and awareness of the engineering profession (PLO4) with learning contexts outside of the formal curriculum, such as through workplace experiences. Furthermore, the students are aware of the sentiment they feel through the preference of informal contexts as opposed to formal curriculum (Table 5). Further work is required to understand the individual circumstances for this association; however, the results suggest that the learning outcomes from an academic context can be enhanced through professional or other work contexts.

Other contexts can be a place for the development of skills and knowledge that are not defined by the PLOs (Walther & Radcliffe, 2006), but it is known that students also supplement learning outcomes defined by the formal curriculum in other contexts (Fitzpatrick et al., 2009; Gutierrez-Bucheli et al., 2022). The results of this work support the claim that students supplement their learning through other contexts, and suggest that in doing so students can develop associations of their learning in those contexts beyond the formal curriculum.

It is important to note that, for a student, universities compete with other aspects of life, both inside and outside of the university. Further work is required to understand the complex web of interactions between the various components of a student’s learning journey—such as how, when or where students benefit from external experiences—and how these interactions lead to an individual achieving program learning outcomes. Beyond merely understanding this network, there is an opportunity to reframe these interactions as a positive place to enhance formal learning by, for example, supporting to students engaging with external experiences to support their independent learning. By supporting students to engage with broader contexts, the university may have more opportunities within the student interaction web.

Conclusion

The research project has used a system engineering lens to test whether constructive alignment holds true in engineering education. By mapping the perceptions students have to the intended PLOs of an engineering education system, the systems engineering lens has found that the elements in the system do not fully map back to the whole. Rather, students perceive some of the intended PLOs in contexts outside of formal curriculum. This project has shown the utility of verifying the PLOs on a degree/program at a holistic level and presents the idea of supporting external environments outside formal curriculum to aid students achieving the intended PLOs.

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