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Development of a competency mapping tool for undergraduate professional degree programs, using mechanical engineering as a case study

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Abstract: Mapping the curriculum of a professional degree to the associated competency standard ensures graduates have the competence to perform as professionals. Existing approaches to competence mapping vary greatly in depth, complexity and effectiveness, and a standardised approach remains elusive. This paper describes a new mapping software tool that streamlines and standardises the competency mapping process. The available analytics facilitate ongoing program review, management, and accreditation. The complete mapping and analysis of an Australian mechanical engineering degree program is described as a case study. Each subject is mapped by evaluating the amount and depth of competence development present. Combining subject results then enables highly detailed program level analysis. The mapping process is designed to be administratively light, with aspects of professional development embedded in the software. The effective competence mapping described in this paper enables quantification of learning within a professional degree program, and provides a mechanism for holistic program improvement.

Keywords: competence mapping; mechanical engineering; assessment; professional standard; cognitive development

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1. Introduction

Professional university degree programs like the Bachelor of Engineering are designed to produce job-ready professionals with a breadth and depth of skills that prepare them for the modern workplace. In contemporary higher education, the curriculum of such a degree program must satisfy a variety of guidelines and regulatory imperatives. Most institutions maintain a list of generic attributes that all graduates from the university must attain. The specific educational purpose of the program is then outlined through program learning outcomes that articulate the targeted disciplinary skills and specialization (Kennedy, Hyland, and Ryan 2007). Professional accrediting bodies also publish standards that list the generic professional competence that all graduates entering a profession must have (e.g. Engineers Australia 2011; Engineering Council 2014; ENAEE 2015; Engineers Ireland 2014). A professional degree program's curriculum must be designed in such a way that each subject contributes to each of these requirements in a coherent way. Curriculum mapping can be used to achieve this, and while significant recent research has focussed on the explicit mapping of curricula to generic attributes (Sumsion and Goodfellow 2004; Oliver et al. 2007; Oliver 2010), or program learning outcomes (Lawson et al. 2013; Lawson et al. 2015), approaches mapping to professional standards are less well-resolved. With accrediting bodies increasingly mandating the explicit mapping of curricula to the professional standards (e.g. Engineers Australia 2008, p. 6), and employers placing increasing value on such transferable employability skills (Deloitte Access Economics 2014), there is a need to standardise competency mapping.

As well as a regulatory necessity, competency mapping can serve a role in ongoing management and improvement of professional degree programs. Mapping is especially effective in identifying curriculum deficiencies or redundancies, and facilitating coherence between collections of subjects (Harden 2001; Sumsion and

Goodfellow 2004; Robley, Whittle, and Murdoch-Eaton 2005a; Robley, Whittle, and Murdoch-Eaton 2005b). A growing number of researchers have also identified the benefits of curriculum mapping as a professional development tool for academics (Sumsion and Goodfellow 2004; Uchiyama and Radin 2009; Gluga, Kay, Lister, Kleitman, et al. 2012; Lam and Tsui 2016). A mapping activity is a powerful way to emphasise the importance of coherent scaffolding of competence development, while also addressing concepts like cognitive development (Bloom 1956; Nightingale, Carew, and Fung 2007), constructive alignment (Biggs 1996; Biggs 2003; Nightingale, Carew, and Fung 2007), and outcomes focussed curriculum design (Walther and Radcliffe 2007). The mapping scheme chosen will dictate how effectively these benefits can be realised.

Current research literature presents a variety of approaches to competency mapping that vary in depth and complexity. The first distinction between these is the resolution of the mapping activity. In limited instances, an entire program will be mapped as a single entity to the professional standard (Perera et al. 2016). In this case, detailed knowledge and expertise is needed by those conducting the mapping to achieve meaningful results. Mapping of individual subjects (Sumsion and Goodfellow 2004; Bath et al. 2004; Spencer, Riddle, and Knewstubb 2012; Arafeh 2015; Lam and Tsui 2016), subject learning outcomes (Gluga, Kay, and Lever 2010; Oliver et al. 2007; Oliver 2010; Chandrasekaran et al. 2013), or each item of assessment (Gluga, Kay, and Lister 2012), is more common. Higher resolution mapping can facilitate more detailed curriculum analysis, but greater time and effort are required to complete the mapping.

Curriculum mapping may also be a qualitative or quantitative exercise. Qualitative mapping involves specification of which competencies are addressed and where, but does not establish the amount or extent of learning (e.g. Harden 2001; Sumsion and Goodfellow 2004; Robley, Whittle, and Murdoch-Eaton 2005b; Robley, Whittle, and Murdoch-Eaton 2005a; Uchiyama and Radin 2009; Arafeh 2015). Qualitative approaches are often inadequate for pinpointing deficiencies or redundancies within a curriculum. Alternatively, quantitative mapping does evaluate the amount of learning associated with each competency. In most published examples of quantitative mapping, assessment percentage is used to weight the map (Oliver et al. 2007; Oliver 2010; Gluga, Kay, and Lever 2010; Gluga, Kay, and Lister 2012), although total student time in learning activities has also been used (Perera et al. 2016). With the potential for variations in time spent by different students, assessment weighting is generally the more consistent measure to use.

Cognitive development or 'depth' of learning is another important curriculum characteristic to be evaluated during mapping. Some tools evaluate this using worded categories such as *Introduced / Developed / Assured* (Lawson et al. 2015), *Declared / Delivered / Learned / Assessed* (Robley, Whittle, and Murdoch-Eaton 2005b; Robley, Whittle, and Murdoch-Eaton 2005a), *Assumed / Encouraged / Modelled / Explicitly taught / Required / Evaluated* (Sumsion and Goodfellow 2004), or *Introduced / Emphasised / Reinforced / Advanced* (Arafeh 2015). These examples focus mainly on assurance of learning and only loosely relate to cognition. Other research uses the more rigorous Bloom's Taxonomy as a measure of the cognitive depth of learning (see Figure 1, Bloom 1956). Gluga, Kay, and Lever (2010) use Bloom's levels to articulate depth subcategories for each generic attribute, while Oliver et al. (2007) and Gluga, Kay, and Lister (2012) use the 6 level Bloom's scale explicitly to define the depth of each component mapped. Bloom's depth descriptors align well with the way engineering competence is developed and the associated emphasis on problem solving.

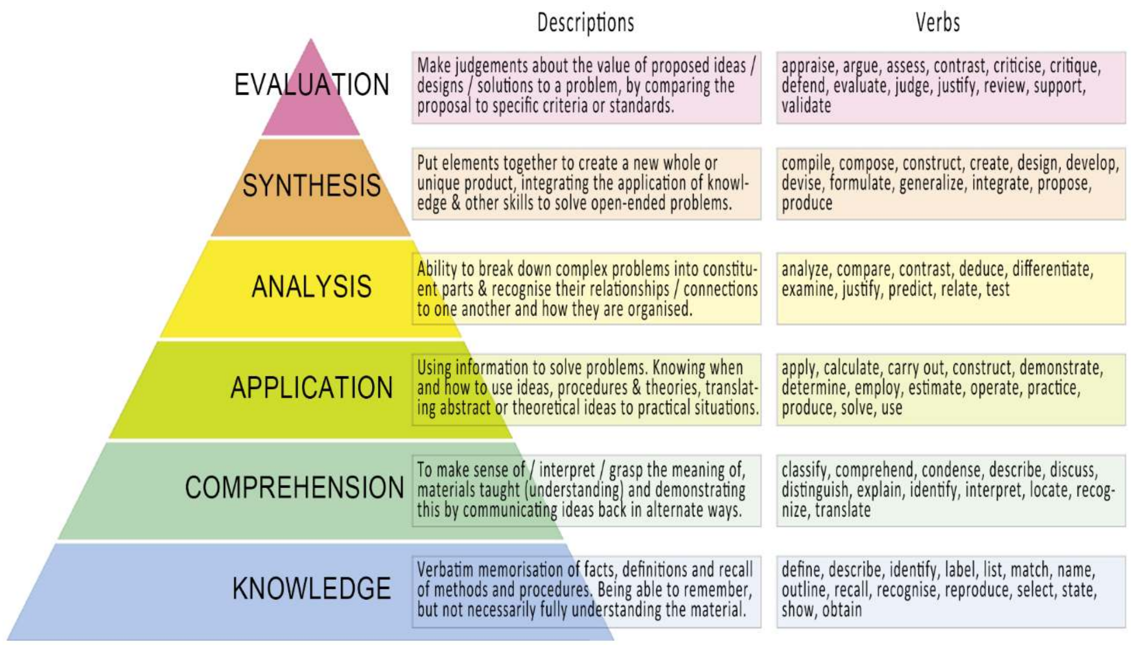

Figure 1. Bloom's Taxonomy, associated level descriptions and useful verbs (adapted from Nightingale, Carew, and Fung (2007), Table 1, page 2).

Finally, the configuration and functionality of the mapping tool plays a key role in its effectiveness. A typical approach is to develop a matrix or table type map (Uchiyama and Radin 2009; Chandrasekaran et al. 2013; Arafeh 2015). Here, subjects and professional competencies constitute row and column headings in a table, and tick marks indicate when a subject addresses a competence. While simple to use and interpret, the amount and depth of learning associated with each tick is not specified. In addition, use of matrix style mapping can "lead to a compliance culture where engagement is limited to 'tick and flick'" (Oliver 2010, p. 18). Other tools incorporate spreadsheet based interfaces (Oliver et al. 2007; Oliver 2010; Lawson et al. 2013; Perera et al. 2016). While more sophisticated, users often find these cumbersome and difficult to engage with; "spreadsheets are a clumsy solution when dealing with data of this nature, size and complexity" (Gluga, Kay, and Lister 2012, p. 93). Other tools implement a web or software based interface affording a greater level of control over the user experience, and generally resulting in more positive feedback from user groups

(Gluga, Kay, and Lever 2010; Gluga, Kay, Lister, and Lever 2012; Gluga, Kay, Lister, Kleitman, et al. 2012; Gluga, Kay, and Lister 2012). The disadvantage of a custom software tool is the software development time necessary.

While a range of mapping schemes have been proposed, those that produce a sufficiently detailed snapshot of competence development also involve labour intensive mapping procedures (see for example Gluga, Kay, and Lister 2012). None have balanced high quality data with an administratively light user experience that encourages ongoing engagement from academics. This paper details the development of an innovative approach to mapping professional competencies that achieves this balance, while simultaneously satisfying regulatory requirements, facilitating ongoing program improvement, and providing a mechanism to improve the way academics engage with teaching and professional competence development. The mapping of an Australian mechanical engineering degree is used as a case study, but the method is equally applicable to a wide range of professional programs across Australia, Europe, and the rest of the world.

2. Mapping Methodology

The mapping approach developed in this work uses a software interface to map Bachelor of Engineering subjects to the Engineers Australia Stage 1 Competency Standards (Engineers Australia 2011). The process follows the procedure summarised in Figure 2 and this sequence is repeated for each subject in a degree program. The software platform is designed to be simple, with integrated instructions and an automated software wizard guiding the user. The details of each step are described in the following sections.

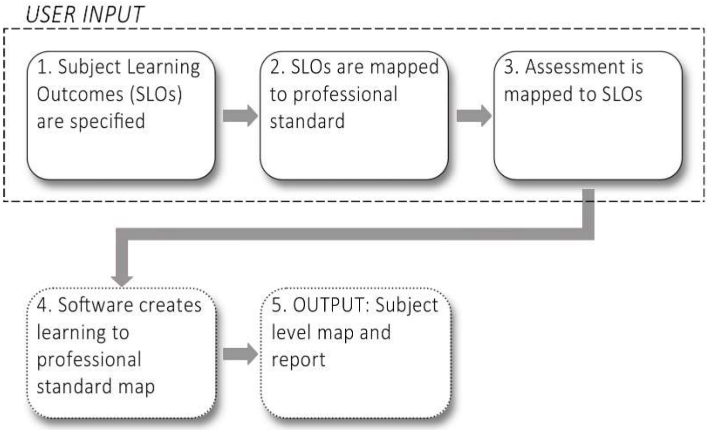

Figure 2. The subject mapping sequence followed by the developed software.

2.1 Specification of Subject Learning Outcomes

To begin the mapping of a subject, the software asks the user to enter between 5 and 7 subject learning outcomes (SLOs). The number of SLOs are limited to encourage clarity of expectation and accurate alignment with assessment methods. Bingham (1999) and Kennedy, Hyland, and Ryan (2007) recommend that an appropriate number of SLOs for a subject is between 5 and 9, while Baume (2009) suggests keeping SLOs as few as possible. In the authors' experience, a maximum of 7 has been found to be suitable for engineering subjects.

To improve SLO articulation, the software includes instructions, references, and a graphic that encourage the use of verbs appropriate to the cognitive demand of each outcome (see Figure 1, Bloom 1956; Orey 2009; Nightingale, Carew, and Fung 2007). The importance of writing effective SLOs is treated in detail by Kennedy, Hyland, and Ryan (2007). When used to develop or update SLOs, this phase of the mapping activity can be an authentic professional learning experience for academics around SLO articulation and outcomes focussed educational design (Webster-Wright 2009). This is most effectively realised when conducting the mapping in a workshop setting led by an experienced educational designer.

Using a second-year subject from the Mechanical Engineering program at James Cook University (ME2525 Machine Element Design), an example of SLO articulation is:

Students who successfully complete ME2525 will:

***SLO1. Recognise** and **employ** the fundamental scientific principles of mechanical design (stress, strain, material properties, failure theories, fatigue phenomena, fracture mechanics) to undertake simple analysis problems;*

***SLO2. Apply** analysis theories in the solution of practical design problems addressing the function, design and capacity of actual machine components including prediction of their life and failure;*

***SLO3. Practice** systematic approaches to mechanical design and analysis procedures;*

***SLO4. Implement** standards in the design of machine components, **understand** their purpose, and be **exposed** to examples that highlight how standards are formulated in engineering practice;*

***SLO5. Produce** analysis briefs, design sketches, and assembly and detail drawings that clearly communicate machine element design and analysis.*

2.2 Mapping Subject Learning Outcomes to the Professional Standard

In the next phase of the process, SLOs are individually mapped to the associated professional standard. Figure 3 illustrates how the developed software visualises this three-level hierarchical structure. The left column lists the three top level categories (i.e. 1. KNOWLEDGE AND SKILL BASE, 2. ENGINEERING APPLICATION ABILITY, 3. PROFESSIONAL AND PERSONAL ATTRIBUTES) which expand out to the associated sub-set elements of competence (1.1, 1.2, etc.). Clicking on an element of competence then activates the list of associated exemplars (referred to in the standard as 'indicators of attainment') to choose from in the right column (2.2a, 2.2b, etc.). The mapping selection occurs at this lowest exemplar hierarchical level, as exemplars are the easiest to associate with SLO related tasks. Selection is made by clicking on the exemplar text. Users are free to select as many or as few exemplars as necessary, across all elements of competence, for each SLO.

At this step, an indication of the cognitive depth (referred to as development level or DL) is also specified for each selected exemplar. This measure is taken from a three-level simplification of Bloom's Taxonomy (Figure 4). This simplification has been used to avoid unnecessary complexity within the mapping process, while still capturing an effective snapshot of how cognitive development progresses within a subject or program. The development level (i.e. DL1, DL2 or DL3) that best fits the depth of the demonstrated exemplar is selected from the accompanying drop-down box on the right. This mapping process is repeated for each SLO in a subject.

The level of sophistication possible with a software interface of this type makes the mapping process as user-friendly as is possible, considering the mapping is occurring across some 69 different exemplars (Engineers Australia 2011). A three-level hierarchical structure like this is common in professional standards (Engineering Council 2014; Nursing and Midwifery Board of Australia 2005; Pharmaceutical Society of Australia 2010; Council of Ambulance Authorities Inc. 2010; Occupational Therapy Australia 2010; Australian and New Zealand Podiatry Accreditation Council 2012; Australian Institute for Teaching and School Leadership 2015), although two-level hierarchical structures (ENAEE 2015; Engineers Ireland 2014) are also easily accommodated. Similar mapping procedures using conventional spreadsheet based mapping tools (Lawson et al. 2013), tend to be significantly more arduous and are broadly disliked by users because of their inability to concisely visualise this type of hierarchical data tree.

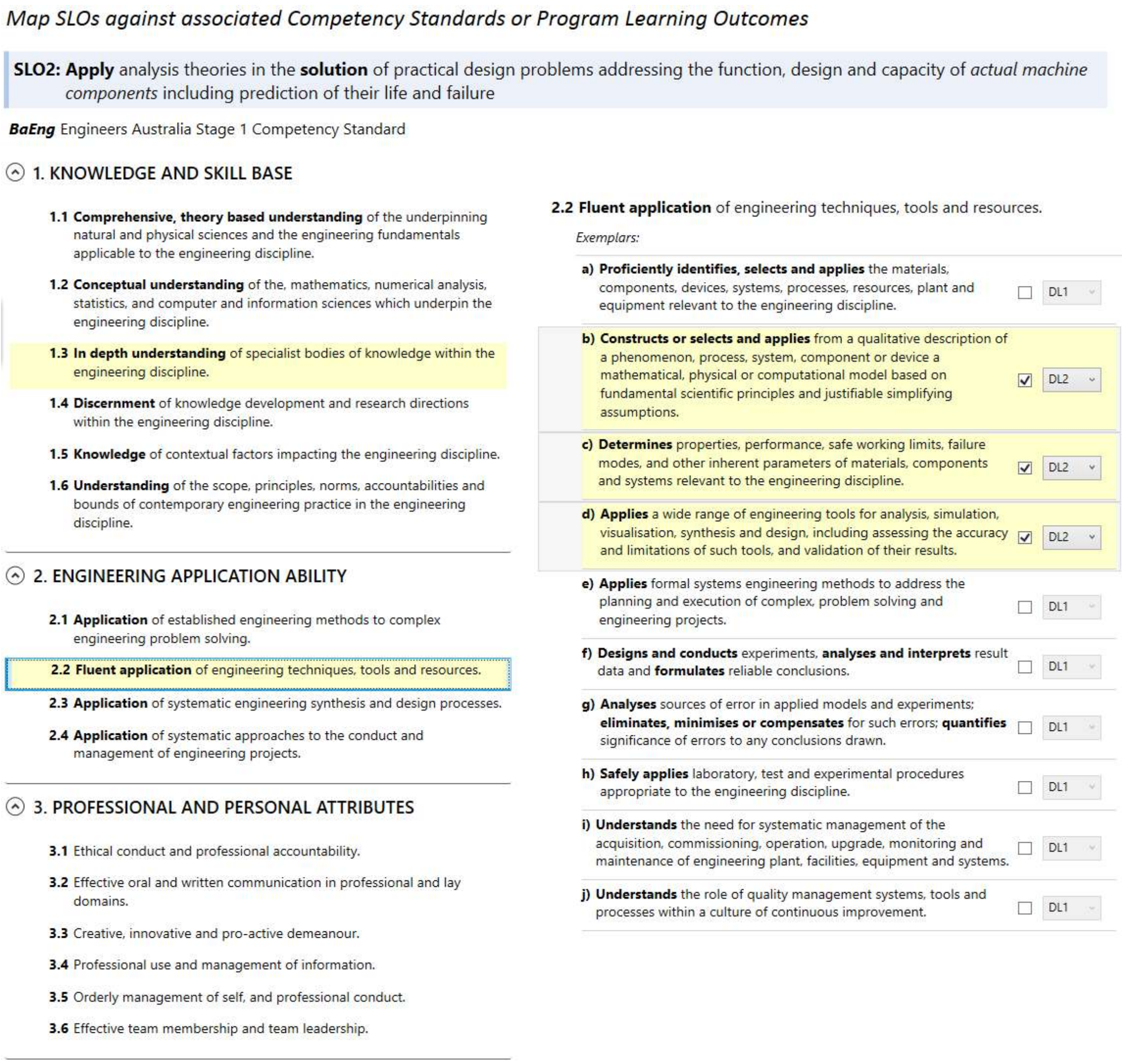

Figure 3. Mapping between subject learning outcomes (SLOs) and the EA Stage 1 Competency Standard.

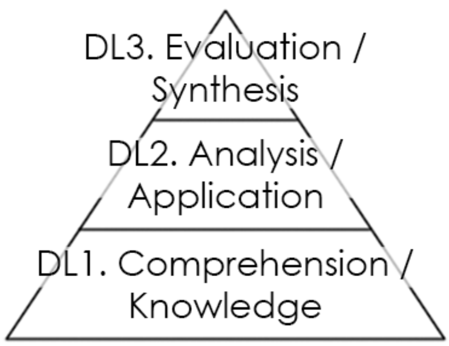

Figure 4. Bloom's pyramid represented via the reduced three development levels (DLs).

2.3 Mapping Learning to the Subject Learning Outcomes

In the third step, assessment is used to quantify the competency map. The software requires that the user provide information on each assessment piece in the subject. A description of each assessment task is provided, along with the associated assessment percentage. Each piece is also grouped into one of 21 available assessment categories:

Exams:

E1: Test/Exam (Invigilated)

E2: Test/Quiz (Non-Invigilated)

E3: Skill Test (Demonstration/Laboratory/Studio/Clinic/Field/Other)

E4: Objective Structured Clinical Examination

Oral & Performance:

O1: Creative Work

O2: Participation/Leadership

O3: Performance (Artistic/Exhibition/Moot Court/Other)

O4: Presentation (Seminar/Debate/Forum/Critique/Other)

O5: Teamwork Performance Evaluation

Written Discourses:

W1: Dissertation/Thesis/Research Paper

W2: Journal (Field/WIL/Laboratory/Reflective/Other)

W3: Portfolio

W4: Poster

W5: Proposal

W6: Report (Experimental/Analytical)

W7: Report (Project/Design/Research)

W8: Review (Literature/Critical)

W9: Tutorial Submission/Workbook/Logbook

W10: Other Writing (Abstract/Annotated Bibliography/Case Study/Essay/Other)

Vocational:

V1: Professional Practice (Planning/Execution/Report)

V2: Software/Manufactured Design/Other Physical Output

Finally, the user must indicate how each assessment task relates to the SLOs. Distribution is expressed in terms of a percentage, and the information required to complete this step would typically be available in marking rubrics, criteria sheets, exam scripts, or a subject's outline. An example of a complete set of data entered at this stage for ME2525 is provided in Table 1. In this example, each assessment piece aligns with one or more of the five SLOs.

Table 1. Example allocation of assessment percentage against SLOs for ME2525. The 'Weight' column must add to 100%, and each row's 'Percentage Breakdown' must add to 100%. As many rows as necessary are created to capture all subject assessment.

Assessment Piece	Type / Category *	Total Weight (%)	Percentage Breakdown (/100% per piece)				
			SLO1	SLO2	SLO3	SLO4	SLO5
Weekly Tutorials	W9	15.0	55.0	25.0	10.0	0.0	10.0
Workshop 1	W7	5.0	5.0	15.0	10.0	45.0	25.0
Workshop 2	W7	5.0	7.5	65.0	7.5	0.0	20.0
Quiz 1	E1	5.0	100.0	0.0	0.0	0.0	0.0
Quiz 2	E1	5.0	50.0	50.0	0.0	0.0	0.0
Quiz 3	E1	5.0	25.0	75.0	0.0	0.0	0.0
Final Exam	E1	60.0	55.0	40.0	0.0	0.0	5.0

* Note: these assessment type abbreviations refer to: E1: Test/Exam (Invigilated), W7: Report (Project/Design/Research), W9: Tutorial Submission/Workbook/Logbook.

Note, assessment is mapped to SLOs in this step, and SLOs are mapped to the professional competency standard in the previous step (Section 2.2). It was considered that a subject coordinator would find mapping assessment to SLOs easier than mapping assessment to competencies directly. The software uses an algorithm to bridge the gap and while a minor amount of accuracy in the data may be lost through this indirect approach (i.e. assessment → SLOs → competencies), the significant gain in ease of use and enhanced potential for staff engagement justifies the choice.

2.4 Determination of the Map Between Learning and Competencies

Once the information of Table 1 has been provided, the software conducts a two-stage process to quantify the competency map for a subject. Because different subjects may contribute different amounts of credit towards the completion of a degree program, credit points are used as the final metric. As an example, a single semester subject at James Cook University, such as ME2525, is worth 3 credit points. As such, the first stage of the calculation uses the assessment map of Section 2.3 to determine how these credit points distribute across SLOs. The second stage of the calculation then distributes the result across the associated professional competencies based on the mapping described in Section 2.2. The algorithm used is detailed as follows.

2.4.1 Credit Points Mapped to SLOs

To determine an alignment between credit points and assessment tasks in a subject, it is assumed that credit points earnt are proportional to the assessment percentage assigned in a subject (for a well-designed, constructively aligned subject assessment percentage should align directly with learning (Biggs 1996; Biggs 2003)). With this provision, the credit point distribution is straight forward. The credit associated with a subject is input and the software determines how this aligns with SLOs based on the assessment percentage information provided in Table 1. An example of this calculation for ME2525 is provided in Table 2. Total credit points associated with each SLO are indicated in bold.

Table 2. Example distribution of a 3 credit point subject (ME2525) across the assessment piece to SLO map of Table 1 and the summed total of credit relating to each SLO.

Assessment Piece	Task Total Credit	Credit Breakdown				
		SLO1	SLO2	SLO3	SLO4	SLO5
Weekly Tutorials	0.45	0.248	0.113	0.045	0	0.045
Workshop 1	0.15	0.008	0.023	0.015	0.068	0.038
Workshop 2	0.15	0.011	0.098	0.011	0	0.030
Quiz 1	0.15	0.150	0	0	0	0
Quiz 2	0.15	0.075	0.075	0	0	0
Quiz 3	0.15	0.038	0.113	0	0	0
Final Exam	1.8	0.990	0.720	0	0	0.090
Total (column sum)	3	**1.519**	**1.140**	**0.071**	**0.068**	**0.203**

2.4.2 Credit Points Mapped to Competencies

With the total credit points associated with each SLO determined, the map between SLOs and the Engineers Australia Stage 1 Competency Standard (Section 2.2) is used to assign this credit point weighting to the associated elements of competence. Table 3 summarises how the mapping software processes SLO credit to competence.

The first four columns summarise the data from the previous steps. The fifth column divides the credit points associated with an SLO evenly across the associated exemplars. This even distribution is a key assumption made by the software and in the absence of a significantly more complex mapping exercise, is a necessary simplification. The credit points associated with each exemplar are then grouped to the parent element of competence level in the last column. While the exemplars facilitate the mapping process, it is the elements of competence that are of key importance in any mapping exercise, hence the grouping.

Table 3. Example data processing for ME2525 based on the SLO to competency map. Note, a single element of competence (like 2.2, DL2 in the example) may get contributions from more than one exemplar and more than one SLO.

SLO (Defined Step 1)	Exemplars Selected (Step 2)	Development Level Chosen (Step 2)	Total Credit Associated with SLO (From step 3)	Credit Distribution	Bar Where Credit is Added
1	1.1 a)	DL2	1.519	1.519 / 1 = 1.519	1.1, DL2
2	1.3 a)	DL2	1.140	1.140 / 4 = 0.285	1.3, DL2
	2.2 b)	DL2		1.140 / 4 = 0.285	**2.2, DL2**
	2.2 c)	DL2		1.140 / 4 = 0.285	**2.2, DL2**
	2.2 d)	DL2		1.140 / 4 = 0.285	**2.2, DL2**
3	1.6 a)	DL3	0.071	0. 071 / 3 = 0.024	1.6, DL3
	2.1 a)	DL2		0. 071 / 3 = 0.024	2.1, DL2
	2.2 e)	DL2		0. 071 / 3 = 0.024	**2.2, DL2**
4	1.6 b)	DL2	0.068	0.068 / 2 = 0.034	1.6, DL2
	2.1 f)	DL2		0.068 / 2 = 0.034	2.1, DL2
5	3.2 b)	DL1	0.203	0.203 / 1 = 0.203	3.2, DL1

The resulting data can be embodied graphically in terms of a three-dimensional bar plot. Bars occur over 2 axes: element of competence in one direction (i.e. 1.1, 1.2, etc.), and development level in the other (DL1, DL2, and DL3). Bar height is determined by the summation of any associated credit. For example, for element of competence 2.2 at DL2 from Table 3 (emphasised in bold), the total height of the bar would correspondingly be:

$$(2.2, \text{DL2}) = 0.285 + 0.285 + 0.285 + 0.024 = 0.879$$

The complete mapping graph for the ME2525 example data of Table 3 is given in Figure 5. The figure provides a clear illustration of how a subject's credit points are distributed across the professional competency standard and at what cognitive development level this occurs. Distribution of assessment types used within the subject is also shown in the figure (input in the third step, Section 2.3).

At the subject level, upon completion of the mapping process, the results are summarised in a PDF report including all input information and the resulting SLO weightings (bold in Table 2) and graphical metrics (Figure 5). Within each subject, the mapping results can be used to assist improvement of SLO articulation, manage and improve constructive alignment, plan and improve the balance of competence achieved, and maintain a balanced assessment strategy. Additional program level analytics are discussed in the remainder of this paper.

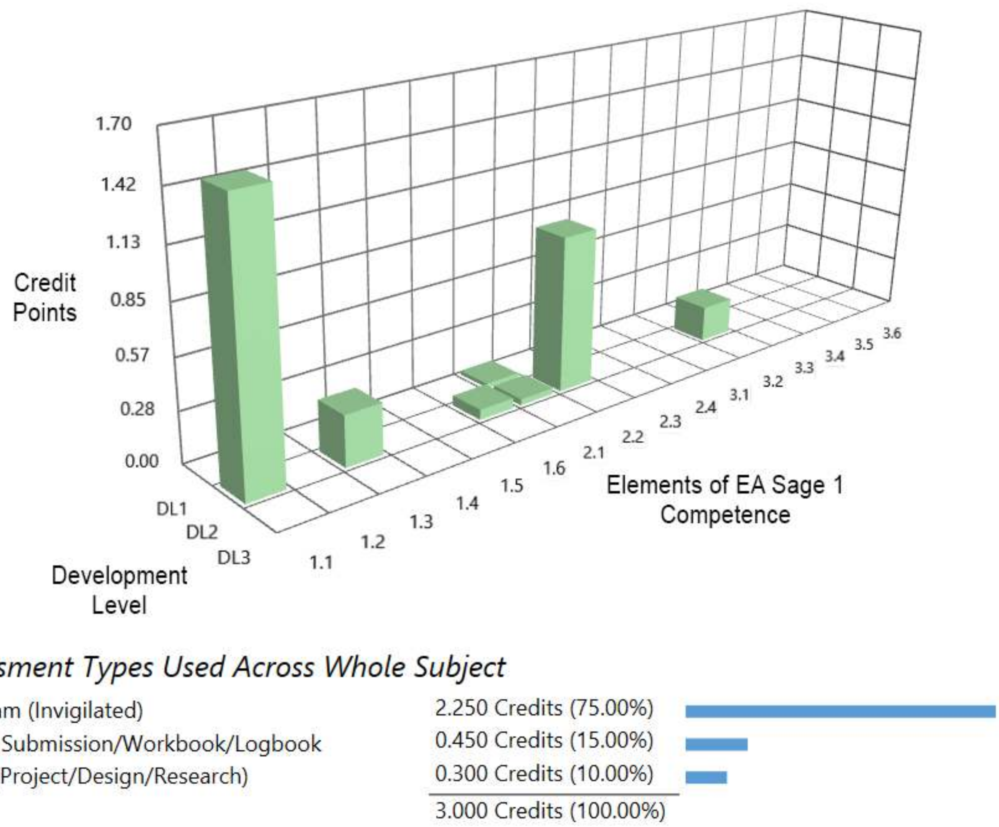

Figure 5. Subject level program output map generated from the information in Table 3 for ME2525 (Machine Element Design) and a visual breakdown summary of the assessment types used in the subject.

3. Program Mapping Results and Discussion

Once all subjects are mapped, the associated mapping data across an entire program can be compiled and input to the analysis side of the software. Several powerful analysis tools and visualisations are possible. Any combination of subjects can be viewed simultaneously, allowing not only whole program analytics, but subset evaluation at the year level, or stream level, or some other combination that is relevant. The program level analyses that are possible using the developed software are outlined in what follows, along with a discussion of the specific results achieved for the mechanical engineering program at James Cook University.

3.1 The Mechanical Engineering Mapping

For combinations of subjects, the bar heights of the individual subject plots (such as from Figure 5) are added together to form the resulting cumulative map. Figure 6 shows the map of all subjects in the mechanical program, while a breakdown of subjects by year level is provided in Figure 7 to demonstrate how competence is scaffolded throughout the degree. Within the software, the bar plot control is interactive and can be rotated and moved to allow easy interrogation of the data. Additionally, hovering over each bar triggers a fly-out menu that indicates which subjects have contributed and in what proportions (see example in Figure 6). An alternative graphical summary of the map is provided in Figure 8 where total program assessment is separated into the corresponding cognitive development levels and grouped by program study period. This figure is used to show how cognitive demand builds throughout the program.

The plots of Figure 6, 7 and 8 provide a powerful summary of the mapping data produced. It is also valuable to produce a more conventional matrix form of curriculum map, especially for accreditation documentation. This form of map is qualitative but the simplicity in interpretation can be valuable. Figure 9 shows the corresponding mapping matrix summary for the mechanical engineering program.

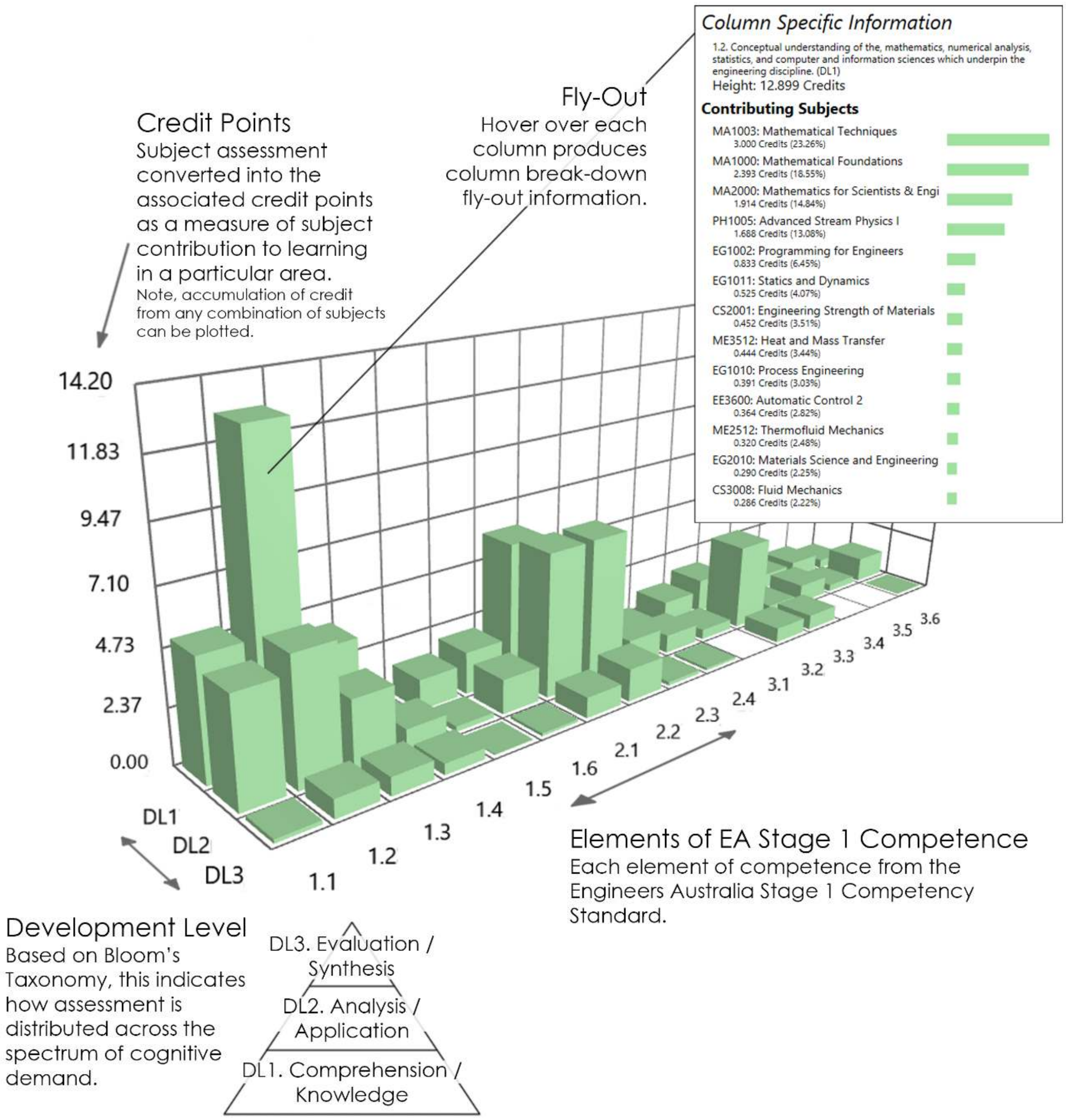

Figure 6. Bar plot mapping result for the Mechanical Engineering program at James Cook University.

The principal difference between a typical matrix map and the one shown in Figure 9 is the inclusion of development level in each mapping tick. This information is already available in the subject level mapping but it is included to strengthen the value of the matrix. From a program analysis standpoint, the evolution of development level throughout the four years of the program can easily be seen from the matrix. In addition, tracing down a column will indicate if development of a particular element of competence is appropriate and allows any underdeveloped competencies to be identified. In this way, the matrix mapping output is a powerful additional resource for program management.

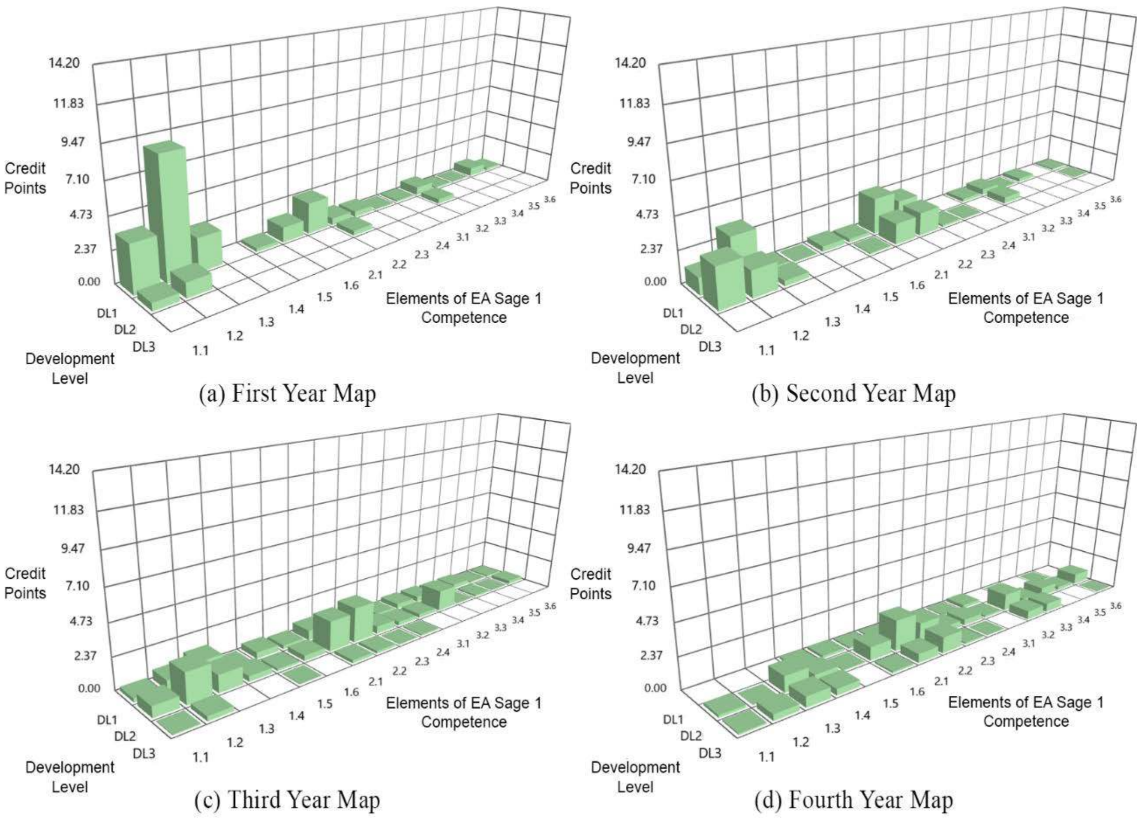

Figure 7. Bar plot mapping result for the Mechanical Engineering program at James Cook University broken down by year level to demonstrate scaffolding of competence.

An important consideration in producing the matrix map of Figure 9 is that a subject’s map may include columns at multiple development levels for a single competency. Only one of these development levels can be shown in the matrix, so choice is made based on the tallest column from the subject map for a given element of competence. Taking the Figure 5 subject as an example, competency 2.1 has columns in both the DL1 and DL2 sections. In this case, a green DL2 mark would be shown in the 2.1 matrix box because the DL2 column is higher than the DL1 column for that subject.

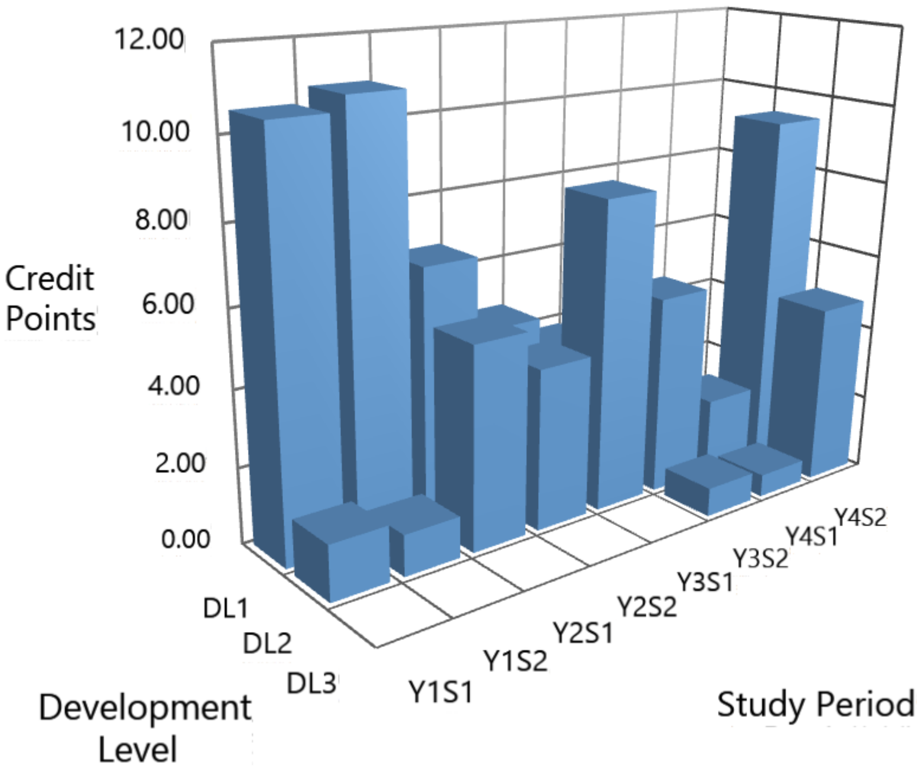

Figure 8. Analysis of development level over the progression of the Mechanical Engineering degree and for assessment modes used (in terms of teaching periods; Y = year, S = semester).

	Subject	Coord	Knowledge and Skill Base						Engineering Application Ability				Professional and Personal Attributes					
			1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4	3.5	3.6
Year 1, S1	EG1000	DH					1	1	1	2		1	1	2		1	1	1
	EG1002	BP		1	1			1	1	1	1		1	1	1		1	1
	MA1000	SB		1														
	PH1005	JD	1	1														
Year 1, S2	EG1010	MS	1	1	1		1	1	1									
	EG1011	HT	2	1				1	1									
	EG1012	OK	1		1				1								1	
	MA1003	PH		1														
Year 2, S1	CS2001	HT	1	1					1	1				1				
	MA2000	SB		1														
	ME2512	YH	2	1					2	1				1				
	ME2521	WL	2	2	1		1	1	2	2	1	2	1	1	1			1
Year 2, S2	EE3600	KL	1	1	2		1	1	1	1	2		1	1		1		1
	EG2010	LY	1	1		1	1		1	1			1	2				
	ME2525	DH	2		2			2	2	2				2				
	Elective																	
Year 3, S1	EG3000	RT					1	1	1	2	1	1	1	2	1	1	1	2
	EG3001	RG		2	1				1	2				1				
	ME3511	RS	2		2	1	1	1	2	2			1	2	1	1	2	1
	ME3515	LY		2	2	2				2	2		2	2				
Year 3, S2	CS3008	WL	1	1	1			1	2	2	2	1	1	2	1	1		1
	ME3512	RG	2	1	1				2	2	2			2		2		2
	ME3525	RG		3	2	2	2	2	3	2	2	2		2				2
	Elective																	
Year 4, S1	EG4011	OK			3	2		2	2	2	2			2	3			
	ME4513	WL	2	3	2	1	1	1	2	2	2	1	1	2	1	2	2	2
	Elective																	
	Elective																	
Year 4, S2	EG4012	OK			3	2		2	2	2	2			2	3			
	EG4013	LY			2			2				2	1	2		2	2	2
	ME4515	RS	2	3	3	2	2	3	3	3	3	2	1	2	3	2	2	2
	ME4522	RS	2		2	1	1	2	2	2				2		2	2	2

Figure 9. Conventional subject to competency mapping matrix for the Mechanical Engineering program with development level indication; blue indicates DL1, green indicates DL2, red indicated DL3.

3.2 Discussion of the Mapping Results

In terms of development level, the Mechanical Engineering program mapping results presented show a smooth transition of cognitive demand. There is knowledge and comprehension focussed assessment in first year, followed by higher level application and synthesis assessment in the final year. The mapping also shows that each element of competence is addressed across multiple subjects, and cognitive demand trends upward for each. This is in line with what would be expected of a four-year professional degree program. It is also evident from the map that most, but not all, elements of competence reach the highest DL3 level. This is in keeping with the interpretation of DL3 as representing an extremely high cognitive demand that might not conceptually fit with some elements of competence at the bachelor level. It is observed that 48.1% of the mechanical program aligns with DL1, 44.3% with DL2, and 7.6% with DL3. While this translates to over two full subjects worth of assessment at the highest cognitive level, future course developments will aim to implement further assessment strategies evaluating DL3 level thinking.

The targeted graduate attributes characterising the James Cook University mechanical engineering program are highlighted by the mapping results. Science, maths and IT fundamentals (1.1 and 1.2), specialist discipline knowledge (1.3), problem solving and implementation of engineering tools in design (2.1 and 2.2), and communication skills (3.2) represent the areas of greatest weighting in the map. These areas are intentional focal points for the program based on the needs of incoming student cohorts, and industry in the region. Peaks in the map ensure that the intended program focus is matched by an appropriate emphasis on assessment in those areas.

The mapping highlights several areas in the program that can be improved and these will be central to planned program enhancements in the future, specifically:

- Competence 1.5 relates to engineering context and is currently assessed predominantly at DL1. Assessment at higher levels of development would be desirable, especially in terms of the business of engineering and sustainability.

- Likewise, competence 3.1 focussing on ethics and accountability requires more authentic assessment modes at higher cognitive levels. Students must effectively demonstrate an ability to apply and evaluate ethical practice, rather than just comprehending what ethical behaviour is.
- Competence 3.3 centring on creativity and pro-active demeanour steps sharply from DL1 in early years, to DL3 in fourth year. A smoother transition with greater opportunity for students to *apply* creativity in the mid years of the program would better equip them with the creativity necessary for more challenging projects in final year.
- Competence 3.6 relating to teamwork skills is underrepresented in the map. In the James Cook University mechanical engineering degree, 7 separate subjects employ team centred project based learning, and team work is used extensively in all other subjects including 23 separate group based experimental investigations. Low weighting in the map indicates inadequate approaches to assessing teamwork and a misalignment between what students are doing, and what they are being assessed on. Effectively assessing team work, especially at higher cognitive levels, is challenging but will be a key focus of future program improvements.

3.3 Analysis and Discussion of Assessment Used in the Mechanical Program

When each assessment item in each subject is input to the mapping software (Section 2.3), the user designates what assessment category the item relates to (i.e. Test/Exam (Invigilated), Report (Project/Design/Research), etc.). This enables analysis of the balance of assessment strategies used throughout a program. Assessment analysis ensures that the modes of assessment used throughout a program are sufficiently varied and representative of the professional skills that an engineering student should develop.

Figure 10 shows the modes of assessment used in the mechanical engineering program, including their relative weights. It is evident that traditional invigilated examination is the dominant assessment mechanism used. This is followed by project/design/research report writing. A variety of other assessment mechanisms also contribute to the assurance of learning across a range of engineering abilities.

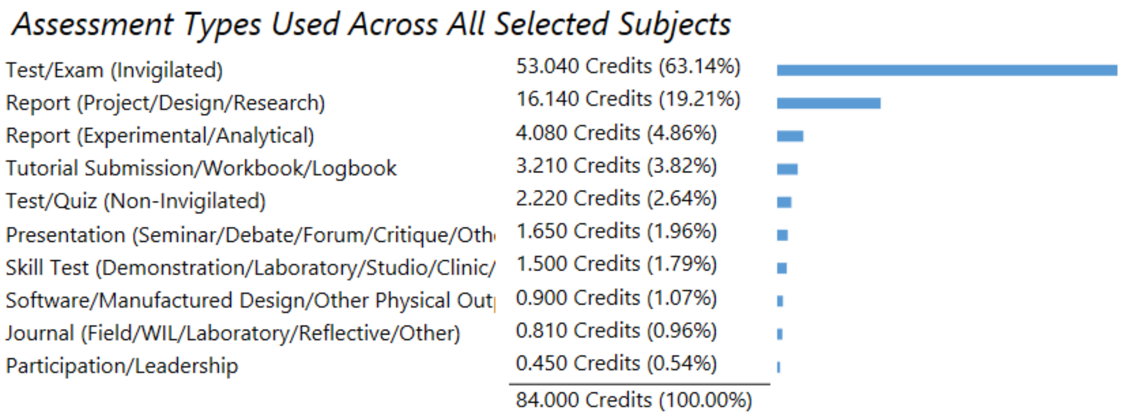

Figure 10. Assessment types used across the Mechanical Engineering program.

Figure 11 presents a development level and study period breakdown which is similar to Figure 8 but specific to the four most used assessment categories. The figure shows decreasing emphasis on examination throughout the program (Figure 11 (a)), and the increasing emphasis on report writing (Figure 11 (b)). This aligns with transition from fundamental skills development to professionally aligned practice. In addition, a balance of laboratory reporting (Figure 11 (c)) is shown throughout the program, and the frequency of tutorial based assessment (Figure 11 (d)) is in keeping with the emphasis placed on fundamental skills early in the program. In all cases, the associated cognitive development transitions from low to high demand throughout the four years of the program. The results do, however, indicate a need to decrease reliance on traditional exam based assessment, in favour of a more diverse and practice oriented assessment schedule. Again, this finding will guide ongoing program improvements.

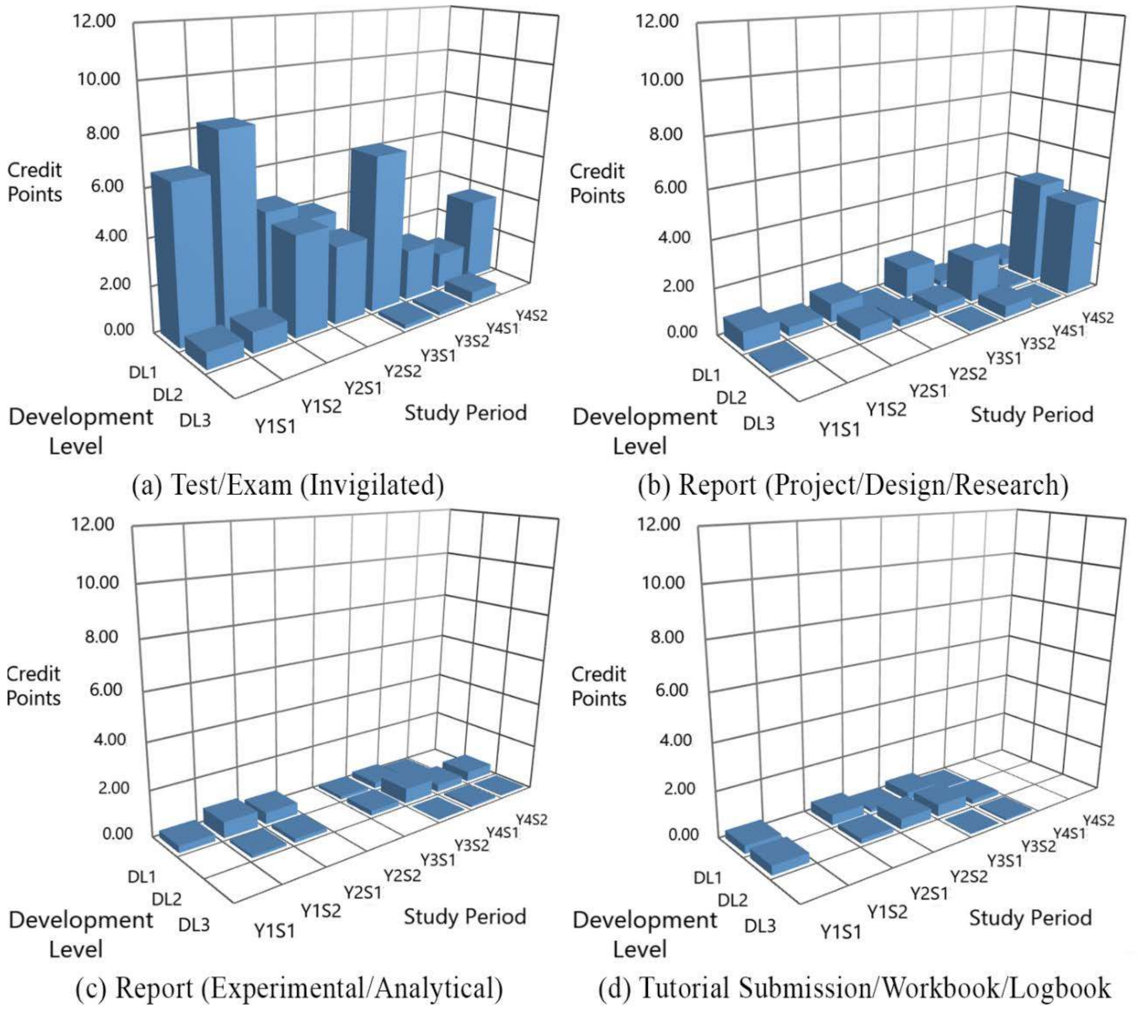

Figure 11. Analysis of development level over the progression of the Mechanical Engineering degree specific to the four most predominant assessment methodologies employed.

3.4 Accreditation

The mapping results and analysis presented here have been used successfully within James Cook University's 2016 accreditation submission. Explicit mapping to the competency standard is required by Engineers Australia, but the way this is used within a program's submission documentation is left largely up to the institution. Engineers Australia do provide guidelines on document structure (Engineers Australia 2008), and the mapping results presented here were used in three key sections.

Within the section titled *Specification of Educational Outcomes*, the mapping results (including Figures 6, 7 and 9) and analysis were used to reinforce how and where certain capabilities are targeted by the program. The map was also analysed in terms of competence scaffolding and identified areas for future improvement.

Within the section titled *Curriculum*, subsections *Enabling Skills and Knowledge Development*, *In-Depth Technical Competence*, *Engineering Application Experience*, and *Personal and Professional Skills Development*, the mapping results and live software tool (e.g. the column fly-out information sampled in Figure 6) were used to identify which subjects contribute to each of these broad competence categories. This information was used to both inform, and support, discussion in each subsection.

Within the section titled *Approach to Assessment and Performance Evaluation* Figures 8, 10, 11, and the analysis presented in Section 3.3 above were used as a foundation for discussion about assessment strategies employed, again including proposed improvements.

While the work presented in this paper focuses on an Australian engineering degree, professional engineering qualifications are benchmarked internationally through agreements like the Washington Accord (International Engineering Alliance 2014). As such, professional engineering competencies, and regulatory processes, are comparable throughout most of the developed world. This means the mapping approach detailed is equally relevant for use in accreditation submissions to a wide range of accrediting bodies in Europe and around the world.

4. Conclusion

The mapping software described in this paper is a powerful subject and program management tool. It is intended as a living monitor of a program, to be updated whenever a subject or group of subjects change (or used as a design tool to facilitate this change). Accordingly, mapping is positioned as a critical part of ongoing program design, and ensures that coherent competence development is at the fore in all subject planning. Active participation of academics in mapping means the data remains current and is more representative of actual practice. By using the developed software, academics gain fluency in concepts like competence scaffolding, assessment design, constructive alignment, cognitive development, and SLO articulation. These factors all contribute to holistic improvement of engineering program quality.

Curriculum mapping must balance fidelity with the effort and time required to compile the data. In developing the method presented here, significant consideration was given to the user experience. The software's design was based on achieving high value information with the least amount of input from the users. The approach was developed through extensive consultation with stakeholders including subject coordinators; program coordinators; College Deans; Associate Deans of Learning and Teaching; and program course leaders from other universities. The simplicity of the mapping software has been found to encourage the engagement of academic staff. Overwhelmingly positive feedback has been provided by all academics who have used the software (so far deployed across more than 10 programs at several Australian universities).

An Australian engineering degree has been used as the case study for the mapping work presented in this paper. The approach is, however, equally applicable to a wide range of professional degree programs, and in any country with comparable accreditation requirements and processes. In each case, by effectively mapping between a professional degree program and the associated professional competencies, the authentic job-readiness of graduates can be assured.

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