International Journal of Engineering Education Vol. 28, No. 4, pp. 966–981, 2012
Printed in Great Britain
0949-149X/91 $3.00+0.00

Rationalizing Relationships between the Various Sets of Learning Outcomes as a Data Driven Mapping Strategy*

ALCION BENEDICT POPP
School of Electrical and Information Engineering, Building J03, The University of Sydney, NSW 2006, Australia.
E-mail: alcion.popp@sydney.edu.au

DAVID C. LEVY
School of Electrical and Information Engineering, Building J03, The University of Sydney, NSW 2006, Australia.
E-mail: david.levy@sydney.edu.au

SIMON BARRIE
Institute for Teaching and Learning, Carslaw, Building F07, The University of Sydney, NSW 2006, Australia.
E-mail: simon.barrie@sydney.edu.au

The paper begins by introducing a Generic Graduate Level Statement of Learning Outcomes (GGLSOLO), developed at The University of Sydney EIE (Electrical and Information Engineering) department, which has been derived from other commonly used sets, such as the CDIO set of learning outcomes and the revised Engineers Australia NGCS Stage 1 set of learning outcomes. The SORP (Scope Overlap Reduction Process) rationalizing technique will be demonstrated with this degree level set of learning outcomes and in concert with the curricular learning outcomes from the faculty of engineering. Subsequently, the method will be demonstrated for any set of learning outcomes and any set of curriculum learning outcomes.

Keywords: automation; graduate level set of learning outcomes; statements of outcomes; rationalization; validation

1. Background

Engineering education during the second half of the 20th century saw a shift in focus from practice based learning and teaching [1] to scientific based approaches in the 1970s and 1980s, which dominated up to the early 1990s. The latter wave was driven by academics who specialized in scientific research, and were less interested in the solving of open-ended problems [2]. Pressure from industry in the late 1990s and early twenty first century culminated in calls for a renewed shift in the pedagogy of engineering education at tertiary level and the need to balance core engineering fundamentals with personal, interpersonal and system building skills [3]. Concomitant to this shift in pedagogy, many accrediting bodies also began to emphasize outcome based approaches, including IEAust in Australia and ABET in the USA [4].

Employer satisfaction surveys and reports documented the need to develop skills in communication, problem solving, independent and critical thinking and interpersonal qualities [4]. This need for change led to the development of many revisions to the national standards and generic sets of learning outcome: in Australia the Engineers Australia National Generic Competency Standards (NGCS) [5] and, more recently, the 2008–2011 revision [6] in the United States, the Accreditation Board for Engineering and Technology (ABET) EC2000 criteria [7]; and in the UK the Accreditation Board of Engineers featuring the Engineering Criteria UK (ECUK) [8].

There have also been many other initiatives from various universities or groups of universities. The CDIO syllabus [9] for example, is part of an initiative by a number of universities, including KTH, Linköping and Chalmers in Sweden and MIT in the USA, with the overarching aim of further reform in engineering education.

These changing times and the greater focus on accountability in the development of curricula and their revision from year to year, has caused the widespread development of many different types of degree level sets of learning outcomes and GGLSOLOs. Whether these are in engineering, medicine or any other discipline is not our prime focus here, but rather, we aim to demonstrate more efficient ways of using a given set in a practical situation.

2. Aim

The aim of this paper is to introduce and demonstrate an efficient data driven process named SORP (Scope Overlap Reduction Process), as a systematic way of rationalizing a GGLSOLO. In this work we are not focusing on what the set of learning outcomes is, but rather we accept it as it is in its original state, and we propose using this process to determine its usefulness and to make adjustments to it

* Accepted 22 March 2012.

within the context of the discipline, school or stream that we are most interested in using. Reversing this process, this set will then be useful in other similar streams within the discipline, or in subsequent years.

This will be done by first selecting a few of the streams of engineering education from within the engineering faculty at the University of Sydney, such as electrical engineering, computer engineering or mechanical engineering. The learning outcomes within each of these streams will be manually mapped to the GGLSOLO chosen. Using this mapped data, the SORP process will be used to create a data report on the mappings and the relationships between the various items within the GGLSOLO.

Using this data report, we shall then be able to rationalize the GGLSOLO, by focusing on the hierarchical items within the set that are the most problematic. In context, this may mean that a few hierarchical items may be reduced to one item, whereas other items may be removed altogether or reworded.

Our aim is that the final output of this work is a more robust GGLSOLO, which will then be useful in making sense of and comparing the various streams from within the discipline where the SORP process was undertaken.

In a nutshell, the SORP process is a means of taking any GGLSOLO, contextualizing it or adjusting it in the context of the curricular learning outcomes of the discipline, and then using this adjusted set for all purposes as needed (i.e. accreditation, benchmarking, modelling, etc).

Figure 1 illustrates this process schematically.

In Fig. 1, stage (1), the chosen streams from within a discipline are manually mapped to the chosen GGLSOLO, whichever this may be. In stage (2), the SORP process is invoked, data is gathered and a data report is created. In stage (3), the adjusted GGLSOLO is mapped against other streams or the same streams in subsequent years, in order to conceptualise and better analyse these streams with a view to improving them.

3. Related work

3.1 Deriving sets of learning outcomes (deriving a GGLSOLO)

Over the last decade a great deal of literature has focused on the importance of outcome driven approaches in education [10], with GGLSOLOs often serving as a hierarchical and comprehensive model of what curricula should be like [11]. In papers such as [12], the importance of GGLSOLOs and their descriptors have been emphasized at a general level. At a more detailed level, there has been extensive discussion about the importance of correctly identifying competency levels in the numerous sets, their items and descriptors [13]. George in her paper 'Classical curriculum design' particularly stresses the importance of verbs and the way in which these can be used to determine the level of proficiency, the learning domain, as well as the most likely and appropriate method of assessment [13]. The importance of these descriptors and the verbs used in the syntax of descriptor sentences is heightened by authors such as Leathwood and Phillips, who draw parallels between curriculum mapping against GGLSOLOs, quality assurance and bench-

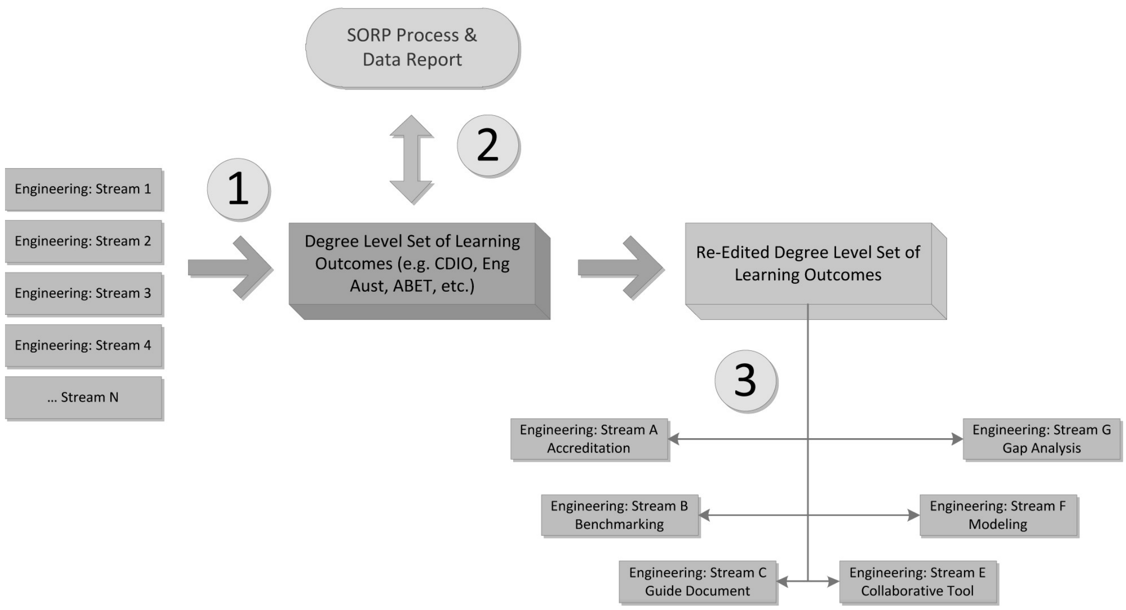

Fig. 1. Illustration of the lifecycle for the SORP process.

marks by which higher institutions can be measured [14].

Given the importance placed on the descriptors of a GGLSOLO, much of the work and innovation in this paper has been directed at this very issue. How can we enhance the usefulness and comprehensibility of a large number of hierarchical descriptors, while still keeping their definition broad enough for use in different disciplines? How can we systematically improve mutual exclusivity among descriptors and reduce the scope overlap using mapped case study data to drive the process? This work has been particularly motivated by papers that describe the current lack of guidance and over-abundant freedom of interpretation given to academics when either developing or mapping their curricula against a GGLSOLO [15, 16, 11].

In developing our own GGLSOLO, for later use in the SORP process, various existing frameworks, syllabi, sets of learning outcomes, methodologies and standards for curricular improvements have been examined, including national standard frameworks, such as: the 'COMP' framework implemented by the University of Montevallo in the assessment of educational outcomes [17], the revised Engineers Australia NGCS at Stage 1 [5, 18], ABET's EC2000 criteria [7], and ABE's ECUK criteria [8]. The EUR-ACE accrediting standards [19] have also been closely examined, as they are a facilitator for transferability in the tertiary sector across the European Union and, hence, a form of accreditation for accrediting standards of various countries. Among the most notable works examined, the CDIO syllabus and its set of learning outcomes have been described as: one of the most detailed single documents of engineering goals [20], as a guideline for curriculum development, and as a framework for programme evaluation [21]. Time has been equally spent on other works that have built on the CDIO initiative, in order to better understand what methodologies were used to achieve the desired changes. Woolacott [22] is one such example, where the author has proposed a revision of the CDIO set of learning outcomes to address issues contending with the range and nature of engineering work. The recent revision of the NGCS Stage 1 competency standards is another example in which the focus has been on building and improving on the previous 2004 statement. The authors, in this later example, have worked to express the competencies more directly with action verbs or verbal nouns, so as to make the statements easier and clearer to use [6, 18].

One of the main pre-suppositions that guides the first part of the work presented, is recommendation number four in King's 'Engineers for the Future' report, which states:

> Enhance staff and material resources to enable delivery of engineering education that is demonstrably aligned with Australia's needs and compliant with international standards [23].

3.2 Validating statements of learning outcomes (validating a GGLSOLO)

The SORP reduction process represents a form of validation of a GGLSOLO to improve its robustness and the validity of its hierarchical items within the context of a particular discipline. In these respects, we have analysed literature on:

- Validation of other GGLSOLOs and reduction techniques
- Curriculum validation and graduate attributes definition
- IT and curriculum mapping techniques
- Curriculum development through systematic approaches
- Academics, stakeholders and the plurality of views.

As recently as 1987 most validation efforts and instruments were focused at the process level, and were less concerned about the outcomes and final content of curricula and statements of learning outcomes [17]. Recently, various validation and item scope reduction techniques have been developed, with most of these focused at the inception of new statements of learning outcomes and curricula. Miles and Huberman, for example, suggest a four step process of underlying key terms, restating key phrases, reducing the phrases and creating clusters for further reduction and labelling [24]. Gonzales *et al.* [10] suggest the use of 'Dynamic Analysis' and 'Factor Analysis' in deriving new sets of learning outcomes from employer expectations of student skills and knowledge. The Dynamic Analysis Reduction Process (DARP) examines the relationship between variables and reduces the number of variables that are related, obtaining only those with a critical influence on the main problem [25, 26]. Factor analysis, also known as 'Varimax Rotation', is similarly used to study the inter-relationship between variables and to factor out the common descriptors [10]. The main issue with some of these methods is the subjectivity in the data. In the SORP process, this has been partly addressed through the aggregation of many courses and streams and hence the development of trends, rather than absolute results.

Currently, most approaches are geared towards the development of new GGLSOLOs. Validation of existing GGLSOLOs through mapping of existing curricula against the GGLSOLO using real case study data is an approach that has hardly been touched upon. This is the essence of what is being proposed in this paper. For this, [27] highlights the limited use of programme mapping in universities, while [28] point to the need for greater programme and learning outcomes evaluation through curriculum mapping.

A number of reasons are identified for this observed reduced effort in mapping the curricula against existing GGLSOLOs. Becher *et al.* identified a lack of transparency and bureaucracy as the cause [29, 30]. Authors, such as Jacobs and Heitmann, argue for the complexity of mapping and the need for the implementation of IT systems [11, 31]. Harden extends the argument and argues for the need to use 'interactive' curriculum maps, continually updated for continued validation [27].

The development of standardized systems that can operate at programme or degree level, rather than subject level is a strongly emphasized trend [4]. Current international projects reinforce this trend, as is the case with the JISC project, running from 2008 through to 2012, aiming for better design and validation of generic statements of learning outcomes and curricula for various disciplines in higher education, using information technologies to inform this process at an institutional level [32]. The work in this paper addresses some of the points raised by Jacobs, Heitmann and Harden, providing a data driven approach to refine the GGLSOLO for subsequent use in further curriculum based mappings.

Comparative and survey research methods have also been used to check the validity of particular GGLSOLOs [22]. The CDIO syllabus, for example, was comparatively analysed to the 'Taxonomy of Engineering Competencies', using the second, third and fourth levels of hierarchical detail [22]. More traditional comparative analysis methods of the CDIO syllabus and its learning outcomes have included comparison against ABET EC2000 criteria, Boeing's engineering criteria, government, industry and other academic statements of learning outcomes [33]. Survey methods have also been popularly used for the CDIO syllabus using stakeholder input, including that from academia and industry leaders to check the validity at the second hierarchical level of detail of the learning outcomes set [1, 9, 34]. The Engineers Australia NGCS Stage 1 Competency Standards for professional engineers has also been recently checked using both comparative and survey research via an extensive methodology, including the mapping of current competencies against international standards, focus group discussions and forums with industry leaders, professional groups and engineering schools [6]. The work presented in this paper makes extensive use of mapping to contextualize and improve the GGLSOLO, using IT tools and methods to reduce the effort required in this process.

It is also the view of some authors that the initial development of GGLSOLOs and their subsequent revision is often based on a plurality of views, lacking a clear theoretical or conceptual base [30, 36–39]. Such work is said to be driven by bargaining processes, rather than the use of scientific and systematic approaches [11]. According to Barrie, this phenomenon is evident from the conglomerate of different level skills and abilities and the lack of interconnectivity between these various skills and abilities [40]. Rompelman and De Graaf [41] suggest that a scientific approach would allow for the implementation of quality control through a technical systems design methodology. Design steps would then enforce quality control in the development and revision of the GGLSOLO. These steps would include: problem analysis, definition of requirements, concept solutions or changes, simulation of solutions or changes and evaluation of final choice [41].

A final idea that keeps surfacing in literature, and which is closely related to the work presented in this paper, is that of concept maps and their documented usefulness in demonstrating structural relationships between concepts [43]. According to Allen, when academics use concept maps to analyse text, they can better determine relationships between concepts. This leads to a greater appreciation of dependencies, which are critical in organizing and developing the curriculum [43]. In a similar way, Allen also describes the carry on benefits of making this data visible to students. While concept maps are not the focus of this paper, the benefits derived from the SORP process are analogous to those derived from using concept maps.

Two statements from recommendation two of King's 'Engineers for the Future' report [44], are particularly relevant to the work on integration and synthesis of GGLSOLOs. These are:

> Refine the definition statements for engineering occupations and graduate qualification standards [23]
>
> Review the graduate competencies and reference standards for the qualifications for each level [23]

4. Initial development of the statement of learning outcomes (developing our GGLSOLO)

The development of our GGLSOLO is designed to pre-empt the central work on the SORP (Scope Overlap Reduction Process) technique, presented in this paper. Moreover, the use of such a generic set of learning outcomes in demonstrating the SORP technique, is meant to illustrate the transferability of this process to other sets of learning outcomes.

Indeed the SORP process is intended to work with any GGLSOLO and, as such, the set chosen is for purposes of demonstration only.

4.1 Why we choose our set

GGLSOLO was chosen and developed in this paper because the statements are in line with international practice based learning, as the set derives from CDIO, ABET2000 and other similar sets. Moreover, the set is also contextual to the Engineers Australia NGCS Stage 1 competencies, making it ideal for use as a model in demonstrating the next stage of contextualization within a local school or discipline environment.

4.2 Underlying standards/sets

The revised Engineers Australia NGCS (National Generic Competency Standards) at Stage 1 [18], is the local standard and is, we thought, most appropriate for developing the GGLSOLO that we use in the SORP process, as it is generic to all engineering disciplines and is also extensively used in the accreditation of engineering schools throughout Australia. There are three main competency domains:

1. Knowledge and Skill Base, which relates to all the fundamental and practice knowledge
2. Engineering Application Ability, which addresses problem solving techniques, responsibilities of engineers, project design issues and business principles
3. Professional and Personal Attributes, which includes elements of effective communication, team work, ethical responsibilities and other professional attitudes.

The CDIO syllabus and its statement of learning outcomes, represents an internationally accepted knowledge and skill component, which we at the department of EIE (Electrical and Information Engineering) at The University of Sydney have merged into our GGLSOLO. The CDIO syllabus and related set of outcomes was considered most appropriate, given the extensive validation that it had undergone in the USA and Sweden [9], as well as its extensive international support from major universities, industry and domain experts. Moreover, the origins of the CDIO framework are partly grounded in ABET's EC2000 criteria, a standard used for the accreditation of engineering degrees in the United States.

Finally, Bloom's Taxonomy of educational objectives was used to analyse the syntax, structure and, most importantly, the semantics of verbs, nouns and adjectives used in the descriptors of the two statements of learning outcomes during the mapping and translation phase. Three important domains have been used in the semantic and syntactical analysis:

- The cognitive domain, dealing with the various levels of knowledge and ability [45]
- The affective domain, dealing with attitudes and feelings [46]
- The psychomotor domain, dealing with various levels and skills of physical movement and perceptual abilities [47].

5. Scope Overlap Reduction Process (SORP)—GGLSOLO validation technique

This is the central topic of the paper, where we demonstrate the method for applying the SORP (Scope Overlap Reduction Process) to a GGLSOLO. In this case we are using our own set [36], developed at EIE (Electrical and Information Engineering) at The University of Sydney.

Using this GGLSOLO, the Scope Overlap Reduction Process (SORP) technique has been developed to:

- observe dependencies among the various descriptors in a GGLSOLO;
- eliminate primarily redundant descriptors (high levels of overlap);
- re-scope descriptors with minor to medium levels of overlap and increase mutual exclusivity between these;
- condense the set of learning outcomes, making it quicker and more accessible, in agreement with the 2011 'Curriculum specification and support for engineering education' report by Robin King and Elizabeth Godfrey [6]; and
- use case study mapping from within a school or discipline to drive the process.

5.1 Methodology

5.1.1 Preparing the data

The Electrical & Information Engineering (EIE) and the Aerospace, Mechanical and Mechatronic Engineering (AMME) programmes were selected as the drivers for the scope reduction process to be developed. The programmes consist of six streams of education for EIE and seven streams for AMME. Each stream consists of between thirty and forty subjects of which most in the first and second year are core subjects and the rest are electives. Most of the core subjects are identical across the various streams. Each of the subjects contains between five and ten learning outcomes. A total of about two-thousand learning outcomes have been mapped against our GGLSOLO's third level descriptors,

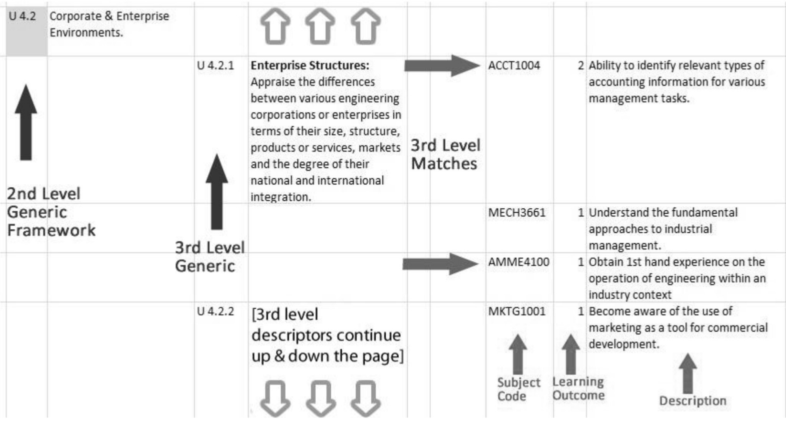

Fig. 2. Mapping process.

of which there are one hundred and eleven (see Table 3 in Appendix A1 for the full set).

Each descriptor in the set was aligned with matching learning outcomes from the aggregate of subjects in the programme streams, using academic input to verify the mapped data. Because each learning outcome is uniquely identifiable from the combination of subject code data and learning outcome number, as shown in Fig. 2, the scope reduction function could be invoked using the mapped data to iterate and determine the relationship between the various items in our GGLSOLO.

5.1.2 Developing the logic and interface

SORP has been designed to determine dependencies between descriptors of a GGLSOLO in an effort to reduce overlap and redundancies within the set. This is done using a statistical computer driven VBA script. The steps involved are described below.

5.1.2.1 Developing the one-dimensional matrix

Every non-commutative combination of 3rd level item pairs must be checked in turn with respect to each of the learning outcomes mapped. A generic set to represent these 3rd level items could be given by:

$$\{U_1, U_2, U_3, U_4, U_5, \ldots U_{n-1}, U_n\}, \qquad (1)$$

where U_k (k can be '1, 2, 3, . . . , n –1, n) represents one third level Unified Code descriptor item.

Combining these items in a non-commutative way, gives the number of combinations needed:

$$\sum_{k=1}^{n-1} k = 1 + 2 + 3 + \ldots + (n-2) + (n-1) = N_{items} \qquad (2)$$

where k represents the set of positive integers up to an upper limit equal to the number of 3rd level items and N_{items} represents the total number of combinations required to analyse all the pairs of items.

From all these combinations, a one-dimensional matrix was developed to hold each of the pairs. This information was organized in a list object (a programmable object), which allowed for the grouping of additional columns and information along side.

5.1.2.2 Developing the scoring algorithm

An algorithm was written to perform two main operations (see Appendix A2). The first part involved compiling the one-dimensional matrix from the current hierarchical structure of our GGLSOLO. This allows the set of learning outcomes to be updated and changed at a later stage without breaking the SORP operation. The algorithm at this point also creates all the non-commutative combinations of descriptor pairs and draws them up into the worksheet as seen in Fig. 3, based on the 2nd and 3rd level hierarchical structure of the set. In the second instance, the algorithm was programmed to score the results. This scoring involves a multi-step process. A high level overview of these steps includes the following:

- Identification of each unique mapped curriculum learning outcome based on subject code and learning outcome number
- Pairing of multiple instances of the same learning outcome across the entire mapped data, where such instances exist
- Score updating of this paired data against the respective matrix entry
- Grouping for inter- and intra-group analysis.

The basic scope behind the second part of the algorithm is to determine which non-commutative pairs of descriptors from our GGLSOLO are repeatedly attracting concurrent mappings of the same curriculum learning outcomes. The important question that is being asked in this instance is:

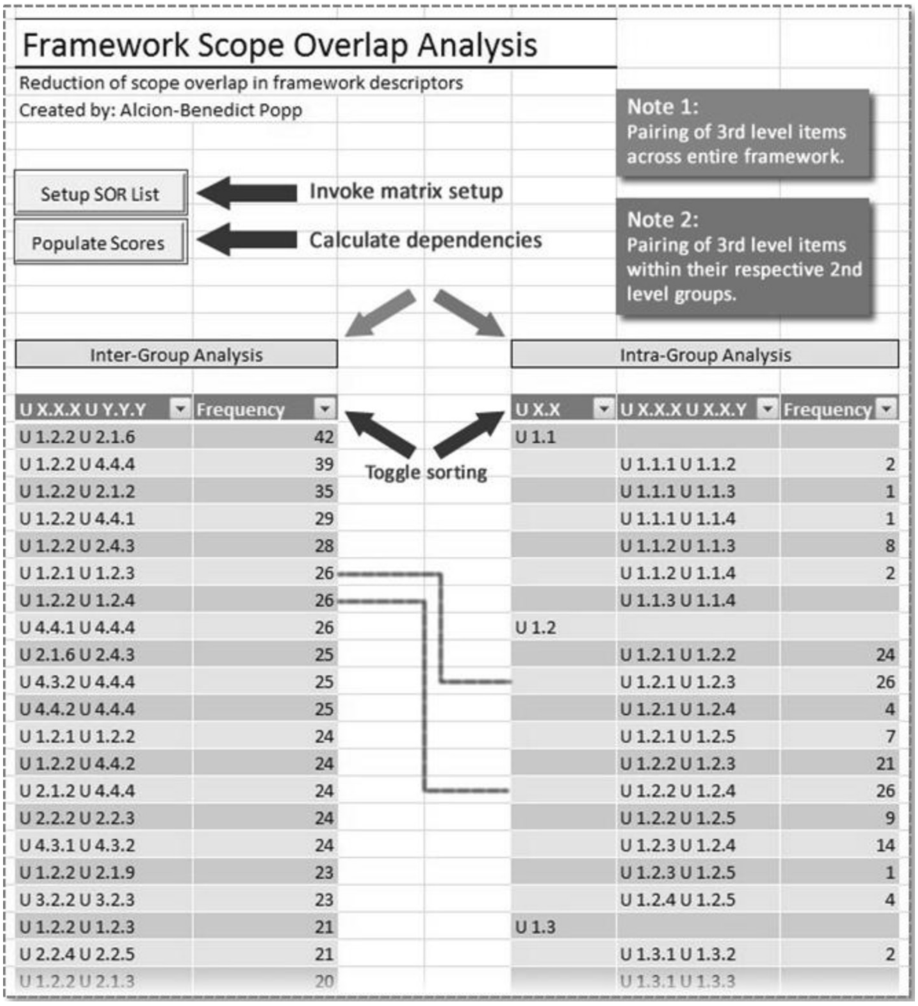

Fig. 3. Scope of overlap reduction process (SORP) interface.

Which descriptors are interpreted most similarly by the user of the generic set during curriculum mapping?

5.1.3 Tabular representation

To display all of the information gathered from the GGLSOLO, the courses and the user, a worksheet has been set up (Fig. 3) featuring two list objects that are directly controlled by the script running the algorithm in VBA code. During operation, the list objects are filled with data and the data can then be subsequently sorted to reveal patterns and trends. For the inter-group analysis, for example, the data has been sorted in descending order by frequency. This brings to the top the items across the entire set that, based on all the curriculum learning outcomes mapped up to that point, are causing most users to interpret them similarly or complementarily.

5.1.4 Interpreting the data

Interpretation of the data can best be done in concert with the examination of the respective descriptors and the role that they play in both the wider and narrower scopes of the GGLSOLO. For instance, a high score of two items on the intra-group analysis could likely indicate complementary competencies rather than scope overlap. Their numerical score or result must be considered in light of their descriptors and their score on the inter-group analysis. The intra-group analysis has purposely been done to take account of the grouping of similar items within a set as dictated by the hierarchy. The two lines connecting from the 'Inter-Group Analysis' to the 'Intra-Group Analysis' in Fig. 3 show the position of the same two items in the two different list objects.

For example, looking at items 'U 1.2.1' and 'U 1.2.3', we observe a score of twenty-six in the SORP process data report (Fig. 3). In other words, there were twenty-six instances in which particular curriculum learning outcomes from the two-thousand plus mapped outcomes were mapped to these two descriptors concurrently. To clarify further, twenty-six different curriculum learning outcomes were concurrently mapped to the two descriptors under question by various academics. These two particular descriptor items (U 1.2.1 and U 1.2.3) can be analysed taxonomically for possible reduction into just one descriptor. An example of this analysis is given in Section 5.2.1.1.

At this point, we must also recognize the inherent weakness of this system in being highly subjective and dependent on the opinion and interpretation of people in driving this process. We are however inspired to trust the trends in the results because of the sheer volume and diversity of users and the fact that the system conglomerates the results together.

By examining the top ranked pairs, a threshold can then be established for items on both the inter-group analysis list and for those on the intra-group analysis list, at which changes to the descriptors may be necessary.

5.2 Taxonomical comparison and translation

When two descriptors are identified with a high score in the SORP process data report (Fig. 3), each of the descriptors from the pair is taken in turn and semantic and syntactical analysis is performed to extract their meanings. Nouns, adjectives and adverbs are used to gauge the subject of the descriptor and the intensity of the action. Verbs are used to perform taxonomical comparison between the two descriptors. The classification is done using Bloom's Taxonomy for cognitive and affective domains [45, 46]. Psychomotor skills are observed using Dave's taxonomy [47]. Best judgement and interpretation should be used wherever a clear cut classification is not possible. The process is demonstrated in examples 1 (5.2.1) and 2 (5.2.2) below.

5.2.1 Example 1: Complementary items

This is an example of items 'U 1.2.1' and 'U 1.2.3', which belong to the same hierarchical group 'U 1.2' and which achieved a score of 26 in the SORP process data report (Fig. 3).

This is an example of complementary descriptors, which may not need adjustment if the size of the set is acceptable. If compaction is a priority, then merging the two descriptors may become a feasible option.

5.2.2 Example 2: Supplementary (overlapping) items

This example is of items 'U 1.2.2' and 'U 2.1.6', which are from different groups and have achieved the highest score in the SORP process data report, as can be seen from Fig. 3. This is an example of two supplementary items, with about 50% overlap.

In this case the two descriptors are supplementary in nature. The first descriptor 'U 1.2.2' is made up of two parts. The first part is the analysis of problems and situations, while the second is the solution of these problems and situations. In comparing the first part of this descriptor with the second descriptor 'U 2.1.6', it is easy to observe that the two are very much alike. Descriptor 1 discusses about the analysis of 'problems', 'situations' and 'challenges'; while descriptor 2 discusses the analysis of 'projects' and 'tasks'. On the concept of analysis, the two descriptors are synonymous, and the relationship is clearly visible from the 'Cognitive classification' and 'Noun, adjective, adverb comparison' sections of Table 2. The connectors indicate the relationship of the various terms based on their synonymous meaning.

Integrally, the second descriptor is more abstract, dealing with the whole wide angle view of projects and tasks, for the purpose of financial estimation and analysis, rather than the actual solution of such projects and tasks. In contrast however, the technical details of how such estimation and analysis would come about is only addressed in the first descriptor, which specifies the use of mathematics, science and engineering science to this extent.

To reduce the overlap between these two descriptors in terms of the analysis component, while avoiding the loss of other exclusive content, such as the solution of problems and the financial and technical considerations, a new descriptor has been formulated. Because this descriptor is all inclusive, the current learning outcomes mapped to the two

Table 1. Taxonomical comparison and reduction (SORP complementary example)

Framework Descriptor 1		*Framework Descriptor 2*		*Output*
U 1.2.1	**Core Knowledge:** Knowledge of the major technical areas comprising at least one engineering discipline.	U 1.2.3	**Material Knowledge:** Knowledge of materials and resources relevant to the discipline, and their main properties.	No Change. Items are complementary within the same group. Core knowledge is theory based, whereas material knowledge is practice based.
Cognitive Classification (brackets indicate the subject)				
Knowledge		Knowledge		
Affective Classification				
Noun, Adjective, Adverb Comparison				
Knowledge Major technical areas Engineering discipline		Knowledge Materials and resources Discipline		

Table 2. Taxonomical comparison and reduction (SORP overlapping example)

Framework Descriptor 1		*Framework Descriptor 2*		*Reduction Output*	
U 1.2.2	**Core Knowledge Application:** Competence in applying mathematics, science and engineering science to the analysis and solution of representative problems, situations and challenges.	U 2.1.6	**Qualitative Analysis:** Ability to assess realistically the scope and dimensions of a project or task, as a starting point for estimating costs and scale of effort required.	U 1.2.2 + U 2.1.6	**Core Knowledge in Analysis & Application:** Ability to integrate mathematics, science and engineering principles with time and financial constraints for the analysis and solution of representative problems, situations and challenges that may constitute a project or task.
Cognitive Classification (brackets indicate the subject)					
Applying (mathematics, science, engineering) = Application Analysis (problems, situations, challenges) = Analysis Solution (problems, situations, challenges) = Application		Analysis = Analysis Assess (project, task) = Synthesis Estimating (cost, effort) = Synthesis		Analysis (problems, situations, challenges) = Analysis Application = Application Solution (problems, situations, challenges) = Application	
Affective Classification					
				Integrate (mathematics, science, engineering principles) = Organisation	
Noun, Adjective, Adverb Comparison					
Core knowledge Mathematics Science Engineering science Representative problems Situations Challenges		Scope and dimensions Project or task Starting point Costs Scale of effort		Core knowledge Mathematics Science Engineering principles Time constraints Financial constraints Representative problems Situations Challenges Project Task	

different descriptors can be transferred over to the new descriptor expeditiously and with minimal or no loss. An added mapping benefit of the new descriptor is the affective component, which uses the ‘organization’ competency on the affective domain to better delineate the requirements of this competency.

5.2.3 Making and merging the changes

Next we need to determine the threshold for the analysis and hence the minimum ‘Frequency’ above which the pairs would need to be analysed as shown in Example 1 (5.2.1) and Example 2 (5.2.2) above. To do this, we sort the ‘Frequency’ column in the SORP process data report in descending order, and then look at the number of times different pairs have the same score in the ‘Frequency’ column, so as to determine how common this score is. For instance, in the example given in Fig. 3, there are single results for frequency scores of ‘42’, ‘39’, ‘35’, ‘29’ and ‘28’. There are then three items with scores of ‘26’ and ‘25’. As we go down the ‘Frequency’ column, the trend becomes intuitively clear. In general we can say that the lower the ‘Frequency’ score, the more instances there are where this frequency score occurs.

To get a better picture and to select a threshold we plot the frequency values from the ‘Frequency’ column of Fig. 3 against the number of times (Instances) that the particular frequency appears in the same data report (see Fig. 4). Two areas of interest quickly become apparent. First, the rectangular area denoted as ‘Critical Area’ in Fig. 4, represents the highest values of the ‘Frequency’ table and must be addressed by the method of taxonomical comparison and translation (Section 5.2). The hexagonal area, denoted as ‘Optional Area’ contains frequency values ranging from 10 to 28. On a practical basis, the items within this range can also be analysed to reduce the GGLSOLO further.

At this point we observe that for frequencies below 10 on the ‘Frequency’ scale in Fig. 4, the curve adopts a more logarithmic behaviour. Because of this increasing trend in the number of instances for particular frequencies, and because the frequencies in this region are so close to each other, these instances can be said to be more common and may be ignored without further analysis.

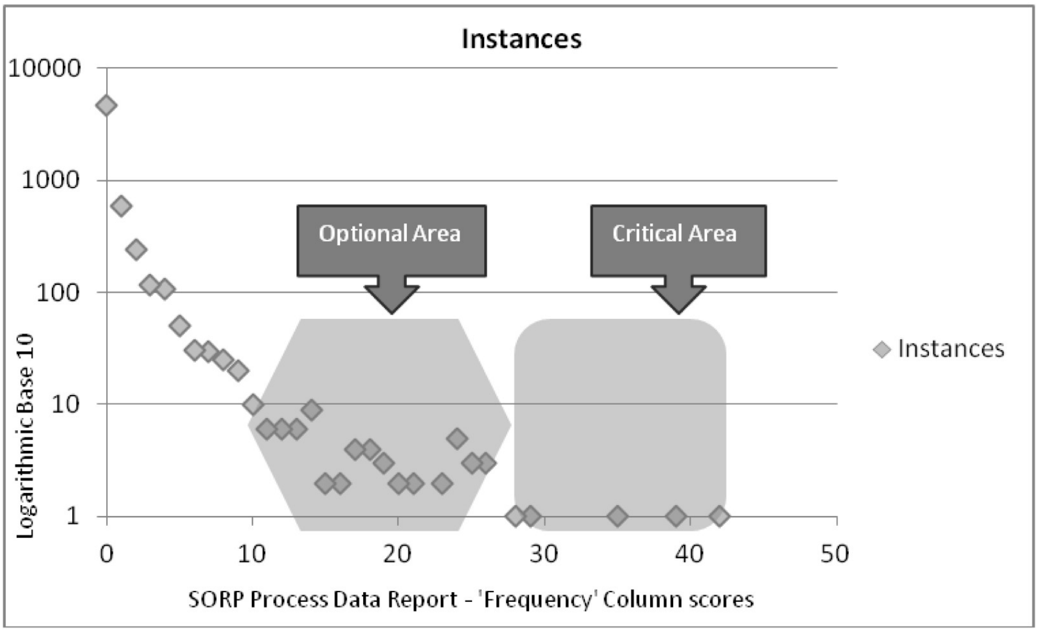

Fig. 4. Instances of same 'Frequency' value.

As part of this approach, it is important to highlight the fact that the process by which we choose a threshold for analysis is not fixed or governed by specific rules. Figure 4 gives a tangible approach to choosing the threshold, in terms of maximizing benefit, while minimizing the number of times the taxonomical comparison and translation (Section 5.2) method must be undertaken. Academics and other users of our tool are free to choose their threshold as tightly or as loosely as they like, depending on the availability of time and the desired level of reduction.

In our particular case, because of time limitations, we undertook the taxonomical comparison and translation analysis (Section 5.2) down to a 'Frequency' score of '20'. We therefore initially considered 22 pairs (44 items). From these, we dropped a further eleven pairs, as the items in these pairs belonged to the same group and we felt that they were complementary in nature most of the time. In total we carefully analysed eleven pairs and from these we reduced 7 pairs. Because in each pair there are two items, the total reduction was of 7 items. In the bigger picture, the GGLSOLO contains 110 3rd level items, and so we achieved a reduction of about 6.4% from analysing the top eleven pairs (22 items). We believe this reduction is significant, as the reduced top items account for a large number of mappings, which would no longer be required.

After this reduction process where two items were condensed into one, the new descriptor item was merged into one of the two groups that contained the original descriptors. Mappings initially linked to either of the items from the pair were then reassessed one-by-one with respect to the new resulting item. This ensured the continued validity of the mappings. This stage required only a minimal amount of academic consultation and was streamlined by the deeper cognitive and affective understanding that had been built up around our GGLSOLO and the curriculum learning outcomes from the various subjects.

5.3 Benefits of SORP and applicability

The SORP process is a step in a whole chain of events or steps that a school or discipline would ideally undertake in order to ensure that the curriculum is well suited to the needs of the school and students from a learning, teaching and assessment point of view. In the first instant, the SORP process can improve the robustness and applicability of a GGLSOLO. In the second instant, this generic, but contextualized, set can then be used repeatedly year after year to conceptualise various streams of education better within a discipline and, hence, affect improvements. These curricular improvements could be geared towards:

- Accreditation efforts
- Improvement of the sequencing in courses within a stream
- Improvement of the relationship between teaching, assessment and learning
- Benchmarking of courses and streams with courses and streams from other universities
- Encouraging collaborative efforts by academics towards curriculum re-development

- Benchmarking with respect to industry demands on graduates.

More importantly, from a general point of view, a GGLSOLO provides the common denominator to undertake all such benchmarking and improvement initiatives. It is a guiding factor when developing new curricula or a checking mechanism when re-developing existing ones.

5.4 Discussion on the contributions

There are some important key contributions of this new approach when contrasted to other techniques that already exist, such as 'Varimax Rotation' [10] and Dynamic Analysis Reduction Process (DARP) [25, 26]. For instance, this validation technique is unique in its use of existing school or faculty curricular data, such as learning outcomes, to drive the SORP process. Secondly, the technique can be applied to both existing and new GGLSOLOs, making it more versatile. The technique thus engages directly some of the future development suggestions and results of papers [6, 27, 28].

The technique directly leverages the incredible power of computers to perform scope overlap validation of an entire curriculum in about ten minutes, addressing the ICT challenge that Heitmann discussed in his paper entitled 'Challenges of engineering education and curriculum development in the context of the Bologna process'. The entire mapping and subsequent synthesis of the set of learning outcomes presents a clean, standardized and systematic approach to achieving a more succinct generic graduate level statement of learning outcomes (GGLSOLO). This is an emphasized trend by renowned papers [4, 27, 41, 48, 49], as well as national reports and forum results, calling for the improvement of the language used in these descriptors and their overall succinctness [6].

Lastly, it has often been discussed in the literature that many existing GGLSOLOs, or those that are mandated by government or other educational bodies of authority, lack relevance to the needs of particular schools, faculties or even universities [30, 36–40, 50–52]. By synthesizing the set of learning outcomes within the context of local school data, as has been done in this technique, the set is also contextually improved with respect to the needs of the environment. Relevant items from within the set are brought to the surface, and redundancies and disused items eliminated. This is in strong agreement with the views of authors such as John Bowden, and Stuart Palmer & Clive Ferguson, who are strongly in favour of the contextualization of generic descriptors [53, 15].

At this point however, we must again emphasize that this approach is not foolproof. Much of the data in the curriculum learning outcomes, as well as the mapping process itself is based on interpretation and the subjective opinions of various course coordinators. With this technique we are using a positivist and scientific approach in a naturalistic inquiry context. We must therefore be especially careful how results are interpreted when the number of collaborators in this mapping exercise is small.

We are, however, confident in the trends that develop from the data, as larger numbers of course coordinators map their courses into the GGLSOLO. Indeed, the technique has been designed with this caveat in mind, and should preferably be used in this way.

6. Conclusions

In this paper, the development of the SORP technique has been set in the context of our generic graduate level statement of learning outcomes (GGLSOLO), a set that inherits from the CDIO syllabus, related learning outcomes and the Engineers Australia's NGCS at Stage 1 for professional engineers. While this particular statement of learning outcomes has been developed locally at the University of Sydney, the applicability of the SORP technique can easily be generalized to any competency based set of learning outcomes (any GGLSOLO). Its use is particularly fundamental in light of the various recommendations, by authors such as Robin King, towards finding new ways to refine engineering graduate attributes, competencies and framework descriptors, to the local needs of schools and faculties throughout Australia.

Curriculum mapping is an exercise that is already being undertaken by many departments as part of their accreditation efforts. Synergies from these mapping efforts have been used in the SORP process. Repeat mapping of learning outcomes has only been undertaken for those items mapped to descriptors that have either been removed or modified as a result of the SORP process, as demonstrated above.

As generic graduate level statements of learning outcomes (GGLSOLOs) grow more common in academia, there is an increased need to find ways to contextualize these quickly to the particular needs of schools and faculties. The technique presented in this paper provides a clear and systematic approach to addressing this problem. While the taxonomical analysis process, as demonstrated in Table 2, can at times be lengthy, the SORP approach has allowed the users to target the most problematic of items, reducing overall effort. Further research is envisaged in this topic, including the development of different sampling methods, such as the combination of more than two descriptor items at a time and the possible automation of the taxonomically driven tabular breakdown of the descriptors.

Acknowledgement—The authors of this work would also like to give a special thankyou to Emeritus Professor Robin King, for his contribution to parts of the work in this paper.

References

1. Edward Crawley, Johan Malmqvist, Soren Ostlund and Doris Brodeur, *Rethinking Engineering Education: The CDIO approach*, Springer, 2007.
2. Göran Gustafsson, Experiences from the transformation of an engineering education introductory project design course into a project design build test course in NordDesign 2004—Product Design in Changing Environment, Tampere, Finland, 2004.
3. N. Bennett, E. Dunne and C. Carre, *Skills Development in Higher Education and Employment*, OU Press, Buckingham, 2000.
4. C. Crosthwaite, I. Cameron, P. Lant and J. Litster, Balancing curriculum processes and content in a project centred curriculum: in pursuit of graduate attributes, *Education for Chemical Engineers*, **1**(1), 2006, pp. 39–48.
5. Alan Bradley, Engineers Australia National Generic Competency Standards—Stage 1 Competency Standards for Professional Engineers, July 2006, Engineers Australia, http://www.engineersaustralia.org.au/sites/default/files/shado/Education/Program%20Accreditation/AMS%20Professional%20Engineer/P05%20Engineers%20Australia%20 National%20Generic%20Competency%20Standard.pdf
6. Elizabeth Godfrey and Robin King, Curriculum specification and support for engineering education: understanding attrition, academic support, revised competencies, pathways and access, Sydney, 2011, Australian Learning and Teaching Council, http://espace.library.uq.edu.au/view/UQ:240702
7. Accreditation Board for Engineering and Technology (ABET), November 2008, ABET, http://www.abet.org
8. Engineering Accreditation Board (EAB). (2008) EAB—The Engineering Accreditation Board, http://www.engab.org.uk/documentation.aspx
9. Johan Bankel, Karl-Fredrik Berggren, Karin Blom, Edward F. Crawley, Ingela Wiklund and Soren Ostlund, The CDIO Syllabus: A comparative study of expected student proficiency, *European Journal of Engineering Education*, 28(3), 2003.
10. Marvin E. Gonzalez, Gioconda Quesada, Kent Gourdin and Mark Hartley, Designing a supply chain management academic curriculum using QFD and benchmarking, *Quality Assurance in Education*, **16**(1), 2008, pp. 36–60,
11. Guenter Heitmann, Challenges of engineering education and curriculum development in the context of the Bologna process, European Journal of Engineering Education, 30(4, pp. 447–458, December 2005.
12. John A. Drexler Jr. and Ilene K. Kleinsorge, Using total quality processes and learning outcome assessments to develop management curricula, *Journal of Management Education*, 2000.
13. Judith W. George, Classical curriculum design, *Arts and Humanities in Higher Education*, 2009.
14. C. Leathwood and D. Phillips, Developing curriculum evaluation research in higher education: Process, politics and practicalities, *Higher Education*, **40**(3), 2000, pp. 313–330.
15. S. Palmer and C. Ferguson, Improving outcomes-based engineering education in Australia, *Australasian Journal of Engineering Education*, **14**(2), 2008.
16. M. Fullan, *The New Meaning of Educational Change*, 3rd edn, Teachers College Press, New York, 2001.
17. James E. McLean, Kathleen A. Bolland, Julia S. Rogers, Patricia S. Ernest and Jerri H. Bullard, A triangulation approach to the validation of the COMP for outcomes evaluation, in *Evaluation '89*, San Francisco, 1989.
18. Engineers Australia, Program accreditation, http://www.engineersaustralia.org.au/about-us/program-accreditation, accessed July 2011.
19. European Accreditation of Engineering Programmes, August 2011, ENAEE, http://www.enaee.eu/the-eur-ace-system/eur-ace-framework-standards
20. L. Woollacott, The goals of engineering education:Arationale for a universal document based on the CDIO syllabus and the taxonomy of engineering competencies, in *3rd International CDIO Conference*, Boston, 2007.
21. Edward F. Crawley, Johan Malmqvist, William A. Lucas and Doris R. Brodeur, Modification to the CDIO syllabus: updates and expansions to include leadership and entrepreneurship, in *5th International CDIO Conference*, Singapore, 2009.
22. L. C. Woollacott, Validating the CDIO syllabus for engineering education using the taxonomy of engineering competencies, *European Journal of Engineering Education*, **34**(6), 2009, pp. 545–559.
23. Robin King, Engineers for the Future: addressing the supply and quality of Australian engineering graduates for the 21st century, Australian Council of Engineering Deans; Australian Learning and Teaching Council; Engineers Australia; the Australasian Association for Engineering Education; and the Australian Academy of Technological Sciences and Engineering, Sydney, 2008.
24. M. B. Miles and A. M. Huberman, *Qualitative Data Analysis: An Expanded Sourcebook*, 2nd edn, Sage Publications, Thousand Oaks, CA, 1994.
25. M. Gonzalez, G. Quesada and T. Bahill, Improving product design using quality function deployment: the school furniture case in developing countries, *Quality Engineering Journal*, **16**(1), 2003, pp. 47–58.
26. J. Forrester, *Industrial Dynamic*, Productivity Press Inc, Portland, 1961.
27. R. M. Harden, Curriculum mapping: a tool for transparent and authentic teaching and learning, *Medical Teacher*, **23**, 2001, pp. 123–137.
28. S. Fallows and C. Steven, Embedding a skills programme for all students, in *Integrating Key Skills in Higher Education: Employability, Transferable Skills and Learning for Life*, Kogan Page, London, 2000.
29. T. Becher, *Academic Tribes and Territories*, Open University Press, Milton Keynes, 1989.
30. J. Clanchy and B. Ballard, Generic skills in the context of higher education, *Higher Education Research and Development*, **14**, 1995, pp. 155–166.
31. H. Jacobs, *Mapping the Big Picture: Integrating Curriculum and Assessment K-12*, Association for Supervision and Curriculum Development, Alexandria,VA, 1997.
32. Joint Information Systems Committee, Effective Practice in a Digital Age, JISC: Supporting education and research, 2009, http://www.jisc.ac.uk/media/documents/publications/effectivepracticedigitalage.pdf
33. P. Armstrong, *UK-SPEK, in Rethinking Engineering Education: The CDIO Approach*, Springer, NewYork, 2007, pp. 58–59.
34. K. F. Berggren, D. Brodeur, E. F. Crawley, I. Ingemarsson, W. T. G. Litant, J. Malmqvist and S. Ostlund, CDIO: An international initiative for reforming engineering education, *World Transactions on Engineering and Technology Education*, **2**(1), 2003.
35. Debra Bath, Calvin Smith, Sarah Stein, and Richard Swann, Beyond mapping and embedding graduate attributes: bringing together quality assurance and action learning to create a validated and living curriculum, *Higher Education Research & Development*, **23**(3), 2004.
36. Alcion Benedict Popp and David C. Levy, A comparison and evaluation of the CDIO reference syllabus against the Engineers Australia competency standards and the development of a new compact framework, in *20th Annual Conference for the Australasian Association for Engineering Education*, Adelaide, 2009, pp. 581–586.
37. I. J. Kemp and L. Seagraves, Transferable skills—can higher education deliver?, *Studies in Higher Education*, **20**, 1995, pp. 315–328.

38. P. Coaldrake, Reflections on the repositioning of the government's approach to higher education. Keynote address, in *Reworking the University Conference*, Brisbane, 1998, pp. 1–17.
39. I. Drummond, I. Nixon, and J. Wiltshire, Personal transferable skills in higher education: The problems of implementing good practice, *Quality Assurance in Education*, **6**, pp. 19–27, 1998.
40. Simon C. Barrie, A research-based approach to generic graduate attributes policy, *Higher Education Research & Development*, **23**(3), 2004, pp. 261–275.
41. Otto Rompelman and Erik De Graaff, The engineering of engineering education: curriculum development from a designer's point of view, *European Journal of Engineering Education*, **31**(2), 2006, pp. 215—226.
42. Paul Stephanchick and Arnin Karim, Outcomes based program assessment: a practical approach, in *Proceedings of the 29th Annual Conference on Frontiers in Education*, Vol. 3, San Juan, Puerto Rico, 1999, pp. 13D1/2-13D1/6.
43. Brockenbrough S. Allen, Computer based mapping for curriculum development, in *Convention of the Association for Educational Communications and Technology*, New Orleans, 1993.
44. Australian Council of Engineering Deans, *Engineers for the Future—addressing the supply and quality of Australian engineering graduates for the 21st century*, Sydney, 2008.
45. Benjamin S. Bloom, Engelhart, Furst, Hill and David R. Krathwohl, *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain*. David McKay Co Inc., New York, 1956.
46. David R. Krathwohl, Benjamin S. Bloom and Bertram B. Masia, *Taxonomy of Educational Objectives, the Classification of Educational Goals. Handbook II: Affective Domain,* David McKay Co., Inc., New York, 1973.
47. R. Dave, Developing and Writing behavioral objectives: psychomotor domain, in *International Conference of Educational Testing*, Berlin, 1967.
48. A. J. Romiszowski, *Designing Instructional Systems,* Kogan Page, London, 1981.
49. S. Waks, *Curriculum Design: From an Art Towards a Science*, Tempus Publications, Hamburg, 1995.
50. S. C. Barrie, Conceptions of generic graduate attributes: A phenomenographic investigation of academics' understandings of generic graduate attributes in the context of contemporary university courses and teaching, 2003.
51. T. Moore and B. Hough, The perils of skills: Towards a model of integrating graduate attributes into the disciplines, in *Language and Academic Skills in Higher Education Conference*, 2005.
52. G. K. Cook, A vector approach to the assessment of undergraduate engineering courses, *International Journal of Engineering Education*, **16**(1), 2000, pp. 3–11.
53. J. Bowden, G. Hart, B. King, K. Trigwell and O. Watts, Generic capabilities of ATN University Graduate, 2000, http://www.clt.uts.edu.au/ATN.grad.cap.project.index.html

Appendix

A1. Statement of learning outcomes

Table 3 contains our GGLSOLO in its entirety. Although this set was primarily developed from the union of the CDIO syllabus, associated learning outcomes and the Engineers Australia NGCS at Stage 1 for professional engineers, there is also a great deal of original content. This original content, which was not derived from any other set of learning outcomes, is underlined.

Table A1. GGLSOLO (Generic Graduate Level Statement Of Learning Outcomes)

U 1	**Fundamental technical knowledge & reasoning**		
	U 1.1	Knowledge of underlying science and engineering fundamentals.	
		U 1.1.1	Mathematical Knowledge
		U 1.1.2	Science Knowledge
		U 1.1.3	Science & Engineering Link
		U 1.1.4	First Principles
	U 1.2	Core engineering fundamental knowledge in at least one engineering discipline.	
		U 1.2.1	Core Knowledge
		U 1.2.2	Core Knowledge Application
		U 1.2.3	Material Knowledge
		U 1.2.4	Material Knowledge Application
		U 1.2.5	Technical and Professional Practice Knowledge
	U 1.3	Advanced engineering fundamental knowledge in at least one engineering discipline.	
		U 1.3.1	Advanced Knowledge
		U 1.3.2	Advanced Knowledge Application
		U 1.3.3	Troubleshooting Capability
U 2	**Personal attributes and engineering knowledge and abilities**		
	U 2.1	Engineering reasoning and problem solving techniques.	
		U 2.1.1	Problem Identification & Assumptions
		U 2.1.2	Initial Solution Formulation
		U 2.1.3	Problem Constraints
		U 2.1.4	Modelling
		U 2.1.5	Estimation
		U 2.1.6	Qualitative Analysis

		U 2.1.7	Analysis with Uncertainty
		U 2.1.8	Originality though Analysis
		U 2.1.9	Synthesis of Solutions
		U 2.1.10	Reflections on Problems
	U 2.2	Engineering experimentation and knowledge development techniques.	
		U 2.2.1	Hypothesis Formulation
		U 2.2.2	Sourcing Information
		U 2.2.3	Assessing & Cataloguing Information
		U 2.2.4	Conducting an Experiment
		U 2.2.5	Analysing Experimentation Results
		U 2.2.6	Hypothesis Verification
		U 2.2.7	Reflections on Knowledge Development
	U 2.3	Holistic and multidisciplinary system approach.	
		U 2.3.1	Multidisciplinary Inputs
		U 2.3.2	Holistic Integration
		U 2.3.3	System Interactions
		U 2.3.4	Emerging System Approaches
		U 2.3.5	Prioritize Driving Factors & Resources
		U 2.3.6	System Solution Tradeoffs
	U 2.4	Critical and innovative thinking and personal attitudes.	
		U 2.4.1	Conceptualisation & Abstraction
		U 2.4.2	Innovative Thinking
		U 2.4.3	Problem Analysis & Partitioning
		U 2.4.4	Development of Logical Argument(s)
		U 2.4.5	Self-awareness
		U 2.4.6	Self-improvement & Learning
		U 2.4.7	Self Presentation & Conduct
	U 2.5	Professional Approach Elements.	
		U 2.5.1	Professional Norms & Customs
		U 2.5.2	Career Planning
		U 2.5.3	Career Development & Action
		U 2.5.4	Awareness of Latest Practice & Technology
		U 2.5.5	Effective Self-Management
	U 2.6	Leadership, Responsibility and Ethical Approach.	
		U 2.6.1	Initiative & Resourcefulness
		U 2.6.2	Decision Making with Uncertainty
		U 2.6.3	Decision Making with Urgency
		U 2.6.4	Ethical Approach & Responsibility
U 3	**Interpersonal and communication skills**		
	U 3.1	Teamworking Elements.	
		U 3.1.1	Team Formation
		U 3.1.2	Team Operation
		U 3.1.3	Team Evolution
		U 3.1.4	Team Leadership
		U 3.1.5	Working in Ambiguous Teams
	U 3.2	Communication Elements.	
		U 3.2.1	Communication Strategy
		U 3.2.2	Communication Construct
		U 3.2.3	Written Communication
		U 3.2.4	Electronic Facilitators of Communication
		U 3.2.5	Elements of Electronic Security in Communication
		U 3.2.6	Graphical Elements of Communication
		U 3.2.7	Oral Communication
		U 3.2.8	Oral Presentation
	U 3.3	Language Protocol.	
		U 3.3.1	World English Standard
		U 3.3.2	Foreign Languages
	U 3.4	Leadership Elements.	
		U 3.4.1	Situation Analysis & Leadership Style Selection
		U 3.4.2	Leadership Strategy & Demeanour
		U 3.4.3	Leadership Function
		U 3.4.4	Espousal

U 4 Conceiving, designing, implementing, and operating systems under various constraints

- U 4.1 Natural and Societal Responsibilities and Constraints.
  - U 4.1.1 Responsibility of Engineers & Projects
  - U 4.1.2 Influence of Engineering & Projects
  - U 4.1.3 Requirements, Regulations and Engineering Standards
  - U 4.1.4 Effect of Contemporary Issues on Engineering
  - U 4.1.5 Effect of Globalization on Engineering
- U 4.2 Corporate & Enterprise Environments.
  - U 4.2.1 Enterprise Structures
  - U 4.2.2 Enterprise Markets, Stakeholders & Strategy
  - U 4.2.3 Management Hierarchy & Function
  - U 4.2.4 R&D in Enterprises
- U 4.3 Conceiving Systems, Processes or Products.
  - U 4.3.1 Transforming Requirements into Goals
  - U 4.3.2 Defining Goals in terms of Deliverables & Function
  - U 4.3.3 Modelling Deliverables & Function against the Goals
  - U 4.3.4 Project Management in Conception & Planning
- U 4.4 Elements of System, Process or Product Design.
  - U 4.4.1 Defining the Design Process
  - U 4.4.2 Design Phases—Preliminary Analysis
  - U 4.4.3 Design Phases—Preliminary Research
  - U 4.4.4 Design Phases—Detailed Solution Design
  - U 4.4.5 Disciplinary Knowledge in Design
  - U 4.4.6 Multidisciplinary Knowledge in Design
  - U 4.4.7 Multi-Objective Compromise in Design
- U 4.5 Implementation Elements of Systems, Processes or Products.
  - U 4.5.1 Defining the Implementation & Production Process
  - U 4.5.2 Implementation Phases—Hardware Manufacture
  - U 4.5.3 Implementation Phases—Software Development
  - U 4.5.4 Implementation Phases —Hardware/Software Integration
  - U 4.5.5 Design & Implementation Verification & Validation
  - U 4.5.6 Implementation Management
- U 4.6 Operational Elements of Systems, Processes or Products.
  - U 4.6.1 Defining the Operational Approach
  - U 4.6.2 Operational Training
  - U 4.6.3 System, Process or Product Life Cycle Scheduling
  - U 4.6.4 System, Process or Product Evolution
  - U 4.6.5 Operational Management
- U 4.7 Management and Entrepreneurship Elements.
  - U 4.7.1 Business Structure & Setup
  - U 4.7.2 Business Capitalization
  - U 4.7.3 Market Identification & Strategy
  - U 4.7.4 Competitor Identification & Strategy
  - U 4.7.5 Product Implementation & Positioning Strategy
  - U 4.7.6 Identifying IP
  - U 4.7.7 Strategy in Protecting IP
- U 4.8 Invention & Innovation.
  - U 4.8.7 Innovation & Applicability
  - U 4.8.8 Invention & Originality

A2. SORP VBA algorithm

The SORP (Scope Overlap Reduction Process) algorithm was developed to accommodate the layout and common use of a typical hierarchical set of learning outcomes or competencies (GGLSOLO) that may at times be subject to change. To this avail, the execution of the script is broken up into three specific phases. The first two phases, namely the compilation of the one-dimensional matrix and the worksheet set-up, are executed as one. The third phase, in which the scoring of results takes place, is executed separately and can be called as needed. The code for this work is not give here, as it is too lengthy. However, a summary of the stages in its operation is given. The code data can be provided on request from the authors of the paper.

The following are the stages of the system:

- Definition of buttons used in the interface of the spreadsheet, including the 'Setup SOR List' button and 'Populate Scores' button. These are added to allow the user to begin the process of automatically developing the list of pairs from the GGLSOLO and then populate this list with the 'Frequency' column results (see Fig. 3).
- Development of the two list objects that hold the non-commutative pairs from the GGLSOLO.
- Populating the 'Frequency' column for these two list objects, through the main scoring algorithm.
- Sorting of the results in the list objects in descending order, to help identify appropriate thresholds for the 'Taxonomical Comparison & Translation' stage as seen at item (5.2)

Alcion Benedict Popp is a Ph.D. student at The University of Sydney in the Electrical and Information Engineering department. His background is in Project Management, Civil Engineering and Commerce (Economics). His primary focus at the moment is in the engineering education field, using new mapping techniques that leverage conformance frameworks and collaborative approaches to drive traceability and other key improvements in the curricula of engineering faculties.

David C. Levy recently retired as director of the Software Engineering program at The University of Sydney and leads the School of Electrical and Information Engineering's CDIO Initiative and is co-Chair of the ANZ CDIO regional group. His current scholarly interests are in real-time distributed systems, server performance engineering, CDIO and in team-project based learning.

Simon Barrie is the Director of Teaching and Learning at The University of Sydney. He is a member of the University's Education Portfolio, which is led by the DVC-Education and he is responsible for leading the collaborative planning and formulation of strategy in Learning and Teaching within the Portfolio. He is responsible for the leadership of the Institute for Teaching and Learning (ITL) and, working with the Heads of the Learning Centre and the Maths Learning Centre, he oversees the strategic direction of all the three units.