A MODELLING FRAMEWORK FOR CURRICULUM ASSESSMENT FOR PROFESSIONAL ACCREDITATION

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ABSTRACT

The assessment of curricula for accreditation purposes is central to much of the effort required for the design and implementation of teaching programs in Schools of Engineering. The CDIO Syllabus provides an example framework that describes these required outcomes. This syllabus has been specifically developed for undergraduate engineering education, offering a range of modelling concepts that can be used for formal curricula assessment. This paper provides an overview of how the CDIO (or similar) competency frameworks can be modelled for a formal analysis to provide an open, objective and repeatable process that may be used as a part of a claim for accreditation. The work presented builds on that developed for the CDIO competency framework and includes some actual case studies using the Engineers Australia Stage 1 Competency Framework. The authors demonstrate the use of a support tool (*CCmapper*) that facilitates this process and provides ways of representing and validating claims for accreditation.

KEYWORDS

competency, assessment, accreditation, curriculum

INTRODUCTION

Accreditation of professional engineering courses is well established internationally through the Washington Accord [1], and in many countries, such as through the Accreditation Board for Engineering and Technology (ABET) [2] in the USA. In Europe, accreditation processes are still developing and will probably come through the EUR-ACE standards [3]. In Australia, Engineers Australia (EA) provides accreditation standards for professional engineers, engineering technologists and engineering associates [4].

Accreditation of a university degree usually requires an analysis of the program of study against a set of learning outcomes, or competencies. It will also require an assessment of capability, resources and processes to support an educational program at an appropriate standard. In this paper we are concerned only with the curricula aspects. The competency frameworks define the standards set by the accrediting authority. These are usually applied to complete programs of study, though sometimes to individuals seeking accreditation outside the usual pathways. The frameworks generally include both generic and discipline specific knowledge and skills.

The elements of a study program (units, courses, subjects, etc) must be carefully reviewed and their learning outcomes mapped to the required accreditation requirements. In broad terms the required outcomes from an engineering program of study will need to cover a wide range of foundation sciences, engineering technologies, design and problem solving as well as personal and professional capabilities. The primary tasks in an accreditation process are to demonstrate that a particular program of study satisfies the requirements of the accrediting authority, as summarised formally in the appropriate reference framework.

The CDIO Syllabus [5, 6] represents one of the more well developed competency frameworks for engineering, and is widely adopted in professional engineering programs, though not predominately in Australia. However, the authors state that a program whose design is based on the CDIO Syllabus will also satisfy its national requirements for specified program outcomes [6], when assessed through a rigorous outcomes-based process. Therefore this syllabus can provide a solid foundation for defining the scope and depth of the required competency elements for the graduate professional engineer and may form the basis for demonstrating that a program is meeting required standards for engineering programs.

However, in making claims for accreditation, there needs to be a detailed assessment of the program, and arguments presented to demonstrate that it satisfies the requirements of the accrediting authority. This analysis needs to be an objective, open and repeatable process if its credibility is to be assured. It also needs to be operationally viable.

In this paper the authors will use the *CCmapper* tool for the assessment and analysis of the CDIO competency framework and show how it can be used as a part of an accreditation exercise. The background to this tool is outlined elsewhere [7].

COMPENTENCY FRAMEWORKS

Competency frameworks for graduate professional engineers are necessarily complex and involve a wide range of skills and capabilities. Typically they are hierarchical, and contain several levels of statements organised into related groups of knowledge and skill. The CDIO syllabus is quite typical in this respect. The four top level parts of the *CDIO Syllabus version 2.0* are shown in Table 1.

Table 1
The CDIO (v2.0) Building Blocks (Level 1)

Section	Building Blocks
1	Disciplinary knowledge and reasoning
2	Personal and professional skills and attributes
3	Interpersonal skills: teamwork and communication
4	CDIO (Conceive, Design, Implement and Operate) systems in the enterprise, societal and environmental context

Each of these top levels includes a number of level two statements that are in turn defined in terms of a number of more detailed statements at level three; and then finally, each of these are described by a set of learning objectives (level four). As a result we have large competency framework with over 400 learning categories/objectives. It is important to note that this decomposition is explicit in order to transition from high level goals (Level 1) to teachable and assessable skills (Level 4) [6].

This hierarchical structure is quite common and similar structures appear in a number of competency frameworks, for example EA Stage 1 Competencies [4], EUR-ACE [3] and the Skills Framework for the Information Age (SFIA) [8].

In this paper we focus our attention on the first version of the CDIO syllabus [5] which has been more formally analysed to establish required levels of proficiency, rather than the second version [6]. In principle the same analysis could be applied to this later version, but not without some additional effort to measure the required levels of achievement for the additional or modified competency elements.

At the most detailed level, the CDIO syllabus items are stated as learning objectives (competencies), and are expressed in the form:

Action Verb + Cognitive Object (or Process).

Some examples from version 1.0 are:

- 2.1.1.a: <u>Evaluate</u> data and symptoms
- 2.2.1.a: <u>Select</u> critical questions to be examined
- 3.1.1.e: <u>Analyze</u> the strengths and weakness of the team
- 4.1.1.b: <u>Accepts</u> the responsibilities of engineers to society.

The action verbs (underlined) describe a *level* of skill or knowledge. This is the cognitive scale that is applied to the object or process. Cognitive scales are derived from learning theory and are generally based on Bloom's Taxonomy of Learning Outcomes [9]. This type of specification is commonly used in competency frameworks.

Table 2
The CDIO Outcome Levels in the Cognitive Domain

Level	Descriptor	Action Verbs
1	To have experienced or been exposed to:	Recall
2	To be able to participate in and contribute to:	Describe, Define, List, Recognise, State
3	To be able to understand and explain:	Discuss, Explain, Interpret, Translate, Locate, Classify, Identify
4	To be skilled in the practice or implementation of:	Apply, Choose, Select, Demonstrate, Execute, Practice, Employ, Use, Utilise, Prepare, Schedule, Analyse, Examine, Appraise, Test, Compare, Discriminate, Reconcile, Elicit, Question, Experiment,
5	To be able to lead or innovate in:	Formulate, Construct, Synthesise, Plan, Create, Evaluate

The CDIO framework proposes a set of modified Bloom levels of outcome as shown in Table 2. The 5 levels roughly align with the original Bloom scale (with the Bloom levels 5 and 6 amalgamated), but the chosen action verbs are moderated to include those particularly relevant in an engineering context.

Based on Bloom's taxonomy, there are three domains of learning that are widely recognised:

1. *Cognitive* domain: concerned with knowledge, comprehension and critical thinking
2. *Affective* domain: concerned with how people react emotionally in situations
3. *Psychomotor* domain: concerned with the ability to manipulate objects.

For the Affective and Psychomotor domains there are other sets of action verbs that may more closely describe the 5 or 6-step scale. The general idea is that the level of capability for a competency is mapped to the 5-point CDIO scale in the required domain, using appropriate sets of action verbs for that domain.

In engineering education the cognitive domain tends to dominate our thinking, but the others can be relevant (and important) in providing the full range of engineering skills. The CDIO framework does identify a small number of competency items that should be assessed in the Affective and Psychomotor domains. It is also suggested in the CDIO Syllabus [5] that the cognitive process elements may be separated out into their own domain (*Cognitive Process*) to assist with the identification of action verbs and associated levels. The choice of domains, or variations, should be done with care to ensure that they align with well established teaching and learning theories.

A part of the CDIO framework (version 1.0) is shown in Figure 1 showing details of the level four items for section 2.1.1. In this figure the action verbs are highlighted. In both versions of the CDIO framework sections 2, 3 and 4 of the competencies are quite generic and could well apply to most engineering disciplines. Section 1 is specifically set aside to accommodate the foundational sciences (1.1), the engineering fundamentals (1.2) and the advanced engineering knowledge for the discipline specialisation (1.3).

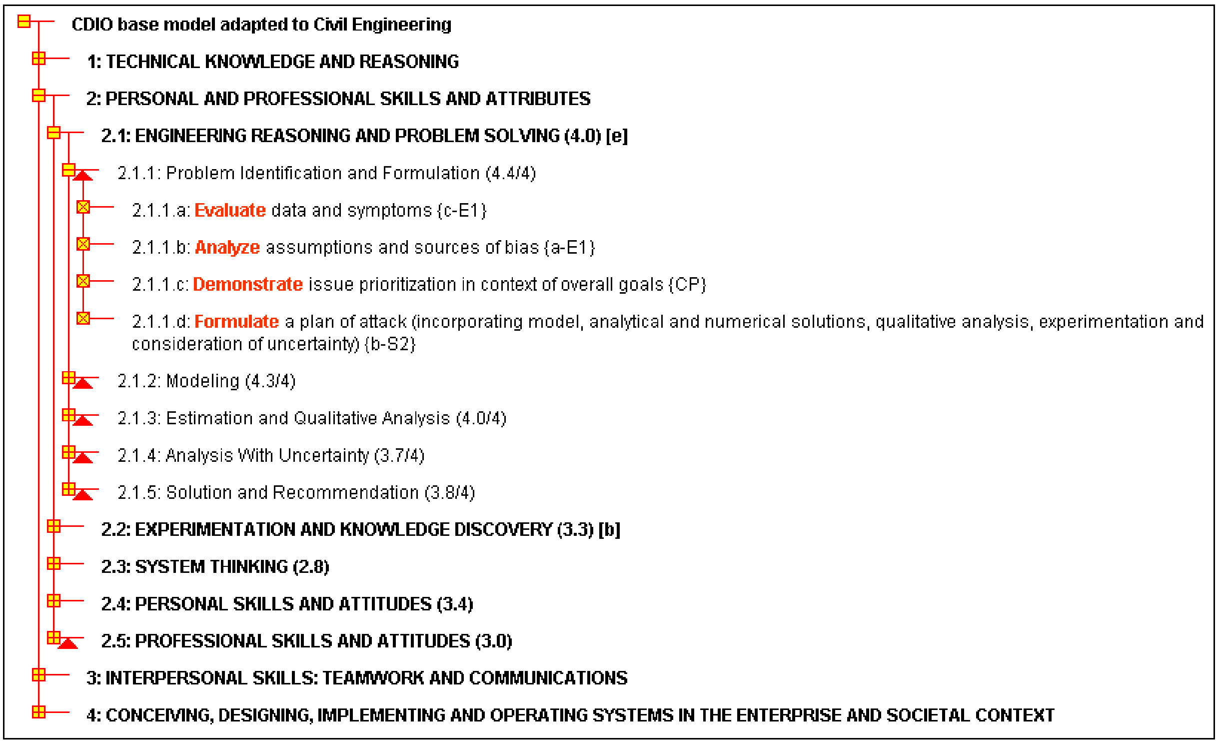

Figure 1. A Part of the CDIO Framework

The leaves of this tree structure define the measurable items in the competency framework. The initial task is to estimate the required proficiency levels for each competency item (at level three) by reviewing the level four items (perhaps taking them as indicators or exemplars of achievement); measuring them on the 5-point scale, then aggregating the results to achieve an estimate of the proficiency at level three. We refer to these assessments as the *targets*. These are the levels of proficiency that are set for the program of study and hence form the benchmarks for achievement (and perhaps accreditation).

For any competency framework to useful in this quantitative way it is necessary to establish the target profiles for the specific programs to be assessed, perhaps along the lines described for the CDIO framework [5]. This will most certainly involve the use of domain experts (practitioners and academics) and will need to be undertaken in a way that the results are credible and generally accepted as representing the accreditation requirements. The second author has been involved in a similar exercise using the competency framework from Engineers Australia [10]. We know it can be done, but not without considerable effort. In that case the results are quite similar (in terms of their general characteristics) to the published CDIO results. These include considerable variations of assessment across assessors and acknowledgement that moderation and averaging processes are generally required to achieve useful results. Clearly, the data from such surveys of domain experts must be carefully managed to assure that the results are meaningful and useful, and are sufficiently credible to be widely accepted as a benchmark for measuring individual programs. Ideally these target assessments should be set or confirmed by an accrediting authority.

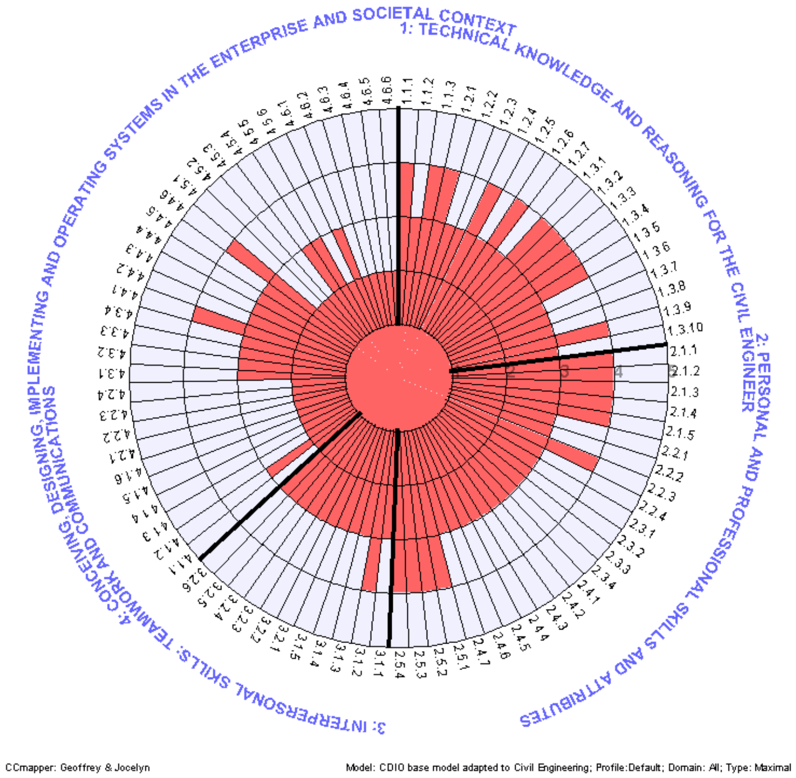

Figure 2. The CDIO Target Values at Level 3

From an extensive survey of both practitioner and academic experts the data for these targets has been measured for the MIT Department of Aeronautics and Astronautics engineering degree program [5]. These results are shown in Figure 2. In this figure we can clearly see the profile and the varying levels of proficiency (on the 5-point CDIO scale) that resulted from this survey. Note that the items in section 1 have been modified by the authors for a specific case study in Civil Engineering and it is the authors' target assessments that are included for that section in this chart.

It is interesting to note some general characteristics of this profile:

- Level 5 is represented at the outer edge of the chart, and level 1 the edge of the innermost circle
- That there are no competency items assessed at level 5 (i.e. it is perhaps rare to expect a professional engineering graduate to have mastered parts of the competency framework)
- Most items are assessed at levels 2, 3 or 4
- There are no items assessed at level 1 (i.e. we expect engineering graduates to achieve more than just being exposed to a competency element).

COMPETENCY ACHIEVEMENTS

Once the set of targets is established and recognised for the relevant engineering degree program, then the next task is to assess the sources of the knowledge or skill that actually results from the program of study. Usually a program is composed of a number (sometimes many) of sources (units, courses, projects, practicums, work episode reports, etc). If each of these is to contribute to the overall achievement of the program then they must be formally assessed.

Generally any single source will make a small number of contributions to the overall achievement as it is typically focused on specialist subject matter. Some, particularly problem-based or project-based sources, may have a wide range of contributions to make. For most university programs, each source will (or should) be accompanied by a set of well defined learning outcomes. Ideally each of these should also be expressed in the form of *Action Verb + Cognitive Object (or Process)*. By using the same assessment scale (i.e. the CDIO 5-point scale) it is then possible to assess these learning outcomes. An example of such a process for the Engineers Australia Stage 1 Competencies for an Bachelor of Technology program has been reported elsewhere [7]. In that case the program is composed of 24 units of study over a three year program.

The process involved in the assessment of sources can be undertaken in various ways for varying levels of granularity, for example:

- In a group activity with persons who have a detailed knowledge of *all* the contributing sources in a program; providing an estimate of the overall outcome from these source contributions to each competency item. This is a particularly demanding approach as it requires the domain experts to have detailed knowledge across the whole program
- For each source (unit, course, etc) within the program the unit coordinator (i.e. person with primary responsibility for the delivery of the unit) is requested to provide the assessments against each relevant competency item for the unit. In this case the unit coordinator is most probably able to achieve the task, but there is a lot more detailed analysis required. This is the preferred approach as it provides a much richer set of data to work with, and provides opportunities for auditing the claims for accreditation (see below).

From the authors experience the second option is probably the most reliable though more time and effort is required. It does, however, also raise some concerns about consistency amongst "assessors", so some moderation may be required. In addition, the "assessors" do need some training and practice with the process. The first approach may be more self moderating as it is conducted as a group activity.

The assessment process for the CDIO framework should involve the following:

- Taking each competency indicator (at level four)
- Assessing the actual level of proficiency by examining the stated learning outcomes (say, from the Handbook description), the local knowledge of the teaching and assessment processes, and the actual content of the unit as delivered
- Aggregating the level four assessments to the level three competency items (this might by a maximal or averaging process)
- Comparing these actual outcomes against the target profile.

A detailed analysis of a complete program on a source-by-source basis from a real case study using the CDIO framework would not be particularly useful within Australia for accreditation, and therefore has not been undertaken. However, to demonstrate how the results might look, the authors have performed an "overall" assessment of a Civil Engineering degree program. A more detailed example of an analysis is reported elsewhere [7].

The result of this example analysis is shown in Figure 3. To interpret this chart:

- The actual assessment of proficiency from the program is shown as a green coloured overlay on top of the target profile (taken from Figure 2)
- The lighter-green sectors indicate where the actual assessments exceed the target values
- The exposed red coloured sectors indicate where the assessments are less than the targets values.

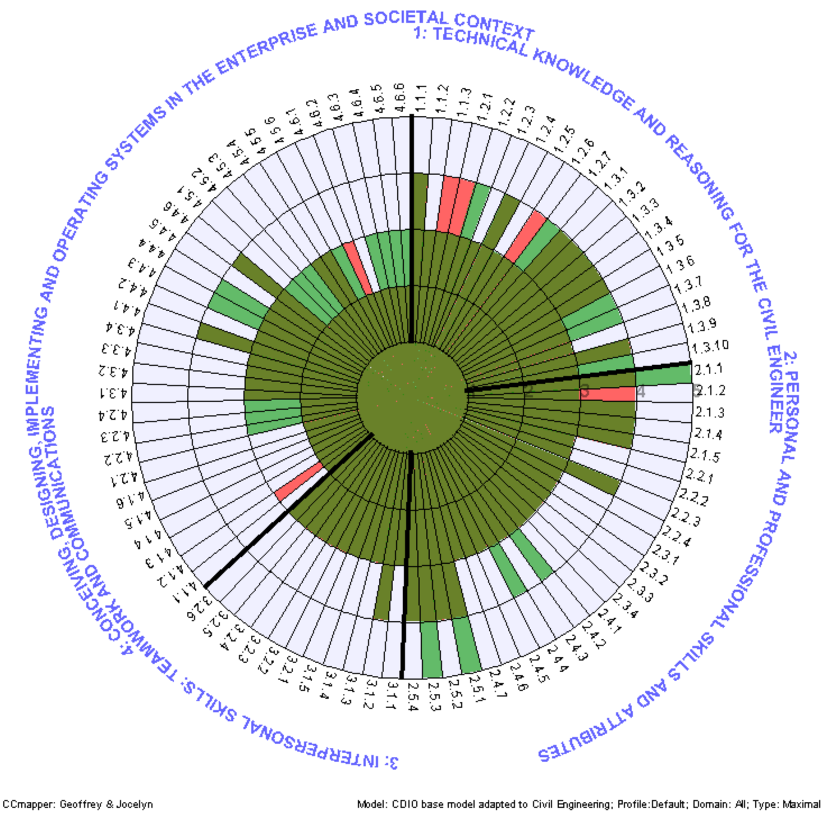

Figure 3. Competency Assessments Overlaid on Targets at Level Three

It is now not too difficult to see how the actual assessments match the targets. Given some guidelines on the levels of compliance (e.g. must satisfy all, must satisfy holistically, etc) then there is a basis for accepting or otherwise a claim for accreditation from this data.

Depending on the required reporting level these results can be also displayed at a higher level (e.g. level 2) by aggregating all the level three nodes to produce results like those shown in Figure 4. Depending on the user requirements aggregations like this can be based on:

1. An average value, on the basis that all child nodes make a contribution to the aggregated value, or
2. A maximal value, on the basis that if a competency is achieved in any one child then it is achieved in the parent.

Figure 4 shows a maximal aggregation.

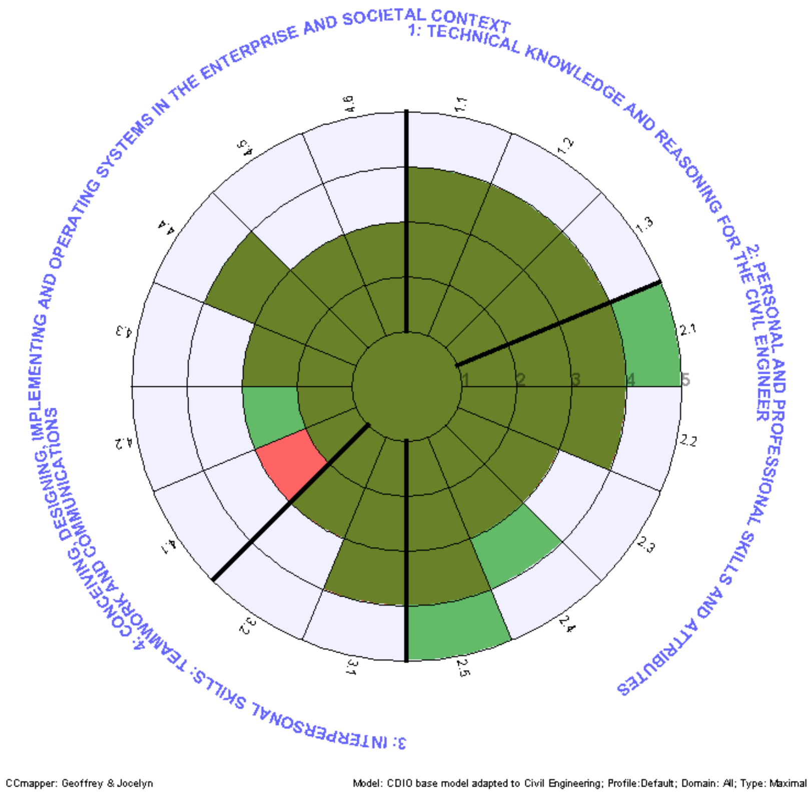

Figure 4. Competency Assessments Aggregated to Level 2

The value of the competency charts as shown in Figure 3 and Figure 4 is that they can be used in a number of ways, for example:

- They clearly identify competency areas that are not being achieved at the required proficiency. This may suggest that changes are required to improve either, or both, the scope or depth of the content of the appropriate sources in the program
- They clearly identify competency areas where the program exceeds the targets. This may indicate a program strength, or perhaps areas from which resources can be redirected to improve outcomes in other areas
- They can form the basis of a decision on accreditation.

As a result we have a clear statement of outcomes that should prove useful to both institutions claiming accreditation as well as the authorities undertaking the accreditation process.

AUDITING ASSESSMENTS

The analysis described above provides a way of presenting assessments of a program against a competency framework - but in a summary form. From an accreditation perspective these claims must be auditable. To achieve this, audit trails must be identified and be able to be presented as a part of the accreditation process. Auditing can only be usefully done if the assessment is being undertaken across all the sources (courses, units, etc) that make up the program being assessed.

Auditing propositions might be put (for example) like this:

- For a nominated competency item, identify all those sources that contribute to this competency (this is a backward trace)
- For a nominate source, identify all competency items that this source contributes to (this is a forward trace).

These traces types are shown diagrammatically in Figure 5.

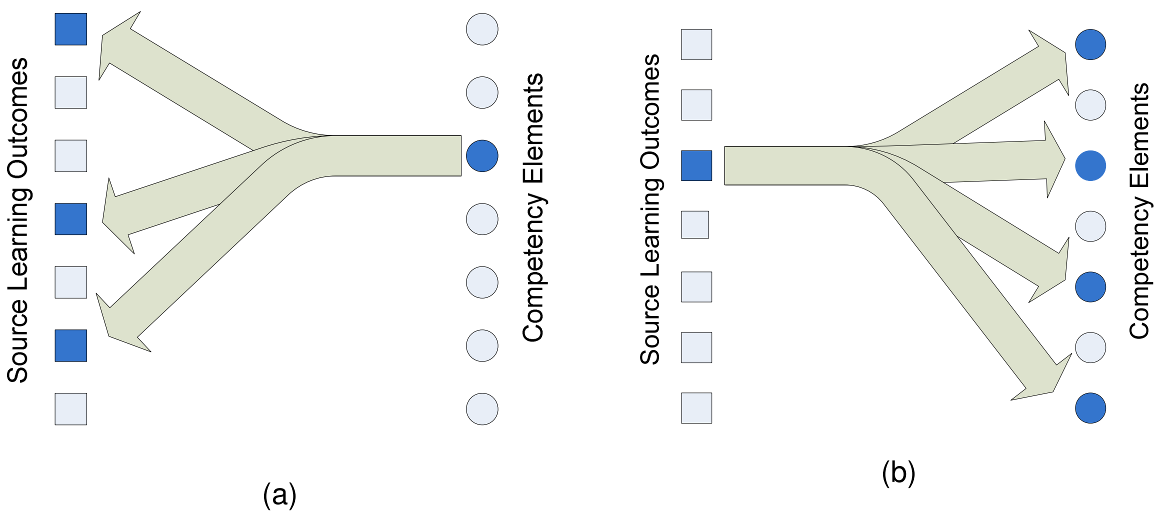

Figure 5. The Auditing Process (a) Backward Trace, (b) Forward Trace

Taken together these tracings provide a solid foundation for validating a claim against the competency framework. The process requires formally mapping the learning outcomes (as provided in the source description) to the appropriate competency item. This is shown in Figure 6 as implemented in *CCmapper*. In this example we are using the Engineers Australia competency framework, though the process would equally apply to a CDIO-based model.

The process involved requires:

- Identification of specific learning outcomes in the source documentation as presented in the text of the Handbook description, or other documentation, of the source
- Linking these text selections to specific competency items

- Providing an proficiency level (what is achieved from the source) on the CDIO 5-point scale).

The *CCmapper* tool provides support to efficiently collect this data while minimising some of the more tedious aspects of the task.

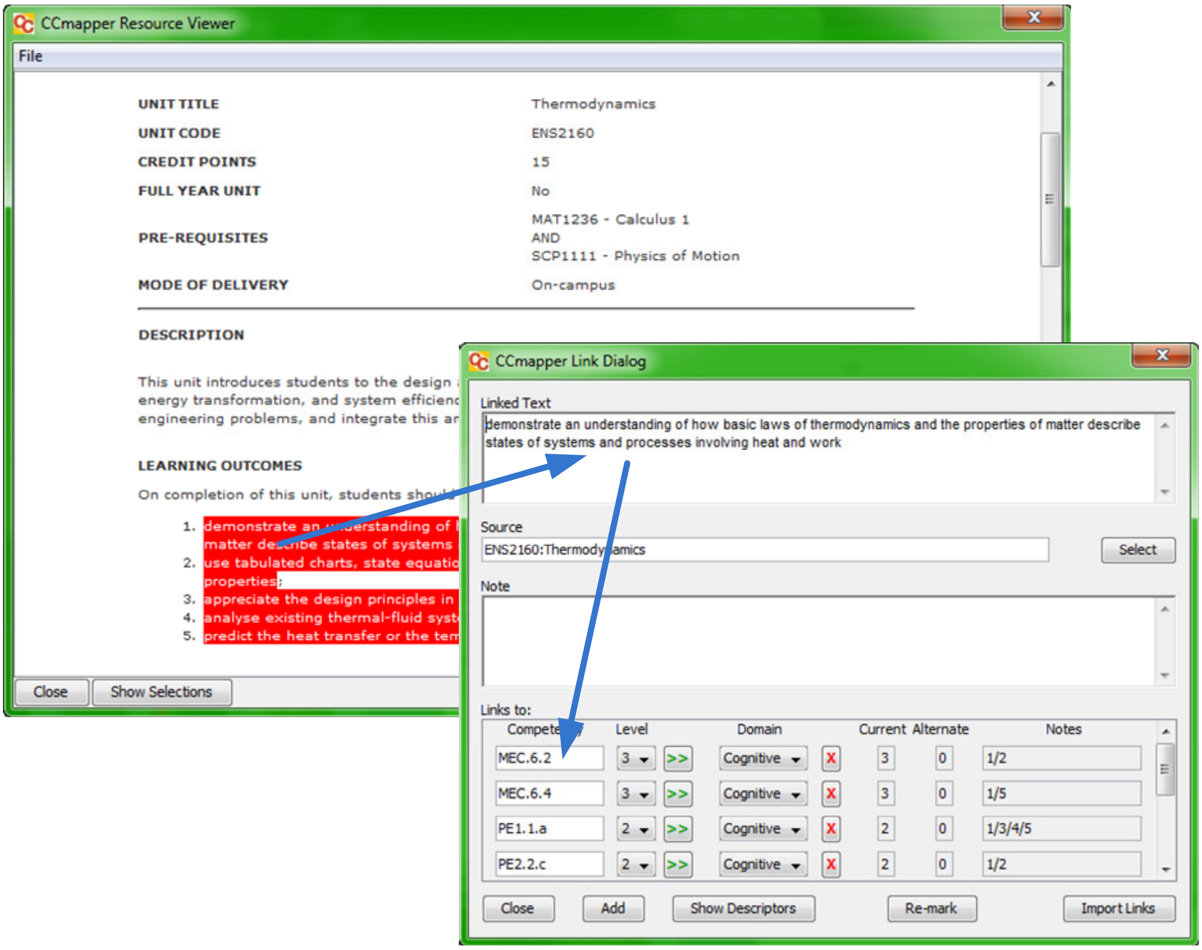

Figure 6. Mapping Unit Outcomes to Competency Items

With this mapping in place the *CCmapper* tool can extract both backward and forward traces. The formal process is described by the authors elsewhere [7].

Table 3
Example Backward Trace

Mapping for PE1.1.a: <Engages> with the engineering discipline at a phenomenological level, applying sciences and engineering fundamentals to systematic investigation, interpretation, analysis and innovative solution of complex problems and broader aspects of engineering practice. [Target:3] Source: ENM3218: Fluid Mechanics [Level:3] Source: ENS1101: Engineering Mechanics [Level:3] Source: ENS1115: Materials and Manufacturing 1 [Level:2] Source: ENS1162: Electrical Engineering 1A [Level:4] Source: ENS2110: Materials and Manufacturing 2 [Level:3] Source: ENS2160: Thermodynamics [Level:2] Source: ENS3180: Finite Element Methods [Level:2] Source: ENS3190: Mechanics of Solids [Level:2] Source: MAT1163: Linear Algebra [Level:4] Source: MAT1236: Calculus 1 [Level:3] Source: MAT2437: Differential Equations [Level:3]

Table 3 provides a sample backward trace. In this case for the selected EA competency item we can report all of the sources (units) that contribute to this competency item and their level of contribution. An accreditation assessor, therefore could easily then go to the source (and any associated resources, including staff) to verify the claims.
Table 4 shows a forward trace (part of) for one of the sources (ENM3218) identified in Table 3. In this case we can see the range of competency items that this unit contributes to. This type of analysis might be particularly useful to unit coordinators who are responsible for planning the scope and depth of the knowledge and skills developed in the unit.

Table 4
Example Forward Trace

Mapping for ENM3218: Fluid Mechanics
PE1.1.a: <Engages> with the engineering discipline at a phenomenological level, applying sciences and engineering fundamentals to systematic investigation, interpretation, analysis and innovative solution of complex problems and broader aspects of engineering practice. [Target:3/Level:3]
PE1.2.a: <Develops and fluently applies> relevant investigation analysis, interpretation, assessment, characterisation, prediction, evaluation, modelling, decision making, measurement, evaluation, knowledge management and communication tools and techniques pertinent to the engineering discipline. [Target:4/Level:2]
PE1.3.a: <Proficiently applies> advanced technical knowledge and skills in at least one specialist practice domain of the engineering discipline. [Target:4/Level:4]
PE1.4.b: <Interprets and applies> selected research literature to inform engineering application in at least one specialist domain of the engineering discipline. [Target:3/Level:2]
PE2.1.a: <Identifies, discerns and characterises> salient issues, <determines and analyses> causes and effects, <justifies and applies> appropriate simplifying assumptions, predicts performance and behaviour, <synthesises> solution strategies and develops substantiated conclusions. [Target:3/Level:3]
PE2.1.b: <Ensures> that all aspects of an engineering activity are soundly based on fundamental principles - by diagnosing, and taking appropriate action with data, calculations, results, proposals, processes, practices, and documented information that may be ill-founded, illogical, erroneous, unreliable or unrealistic. [Target:4/Level:4]
PE2.1.c: <Competently addresses> engineering problems involving uncertainty, ambiguity, imprecise information and wide-ranging and sometimes conflicting technical and non-technical factors. [Target:4/Level:2]
PE2.1.e: <Conceptualises> alternative engineering approaches and evaluates potential outcomes against appropriate criteria to justify an optimal solution choice. [Target:4/Level:3]

These audit reports can be quite extensive and are not suitable for concise reporting. *CCmapper* provides a more compact Mapping Chart as shown in Figure 7. In this example, each source comprising the program is shown across the chart (the columns) and each competency items forms a row. To interpret this chart:

- The target values are shown in the target column of the chart
- A green-coloured cell indicates an assessment for that source against that competency item that is equal to or better than the target level
- A red-coloured cell indicates that the assessment is less than the target
- A empty cell indicates that this unit makes no (or very little) contribution to the competency
- By scanning across a row we can see where the competencies are being achieved (or claimed)
- By scanning down a column we can see what contributions a source is making to various competencies.

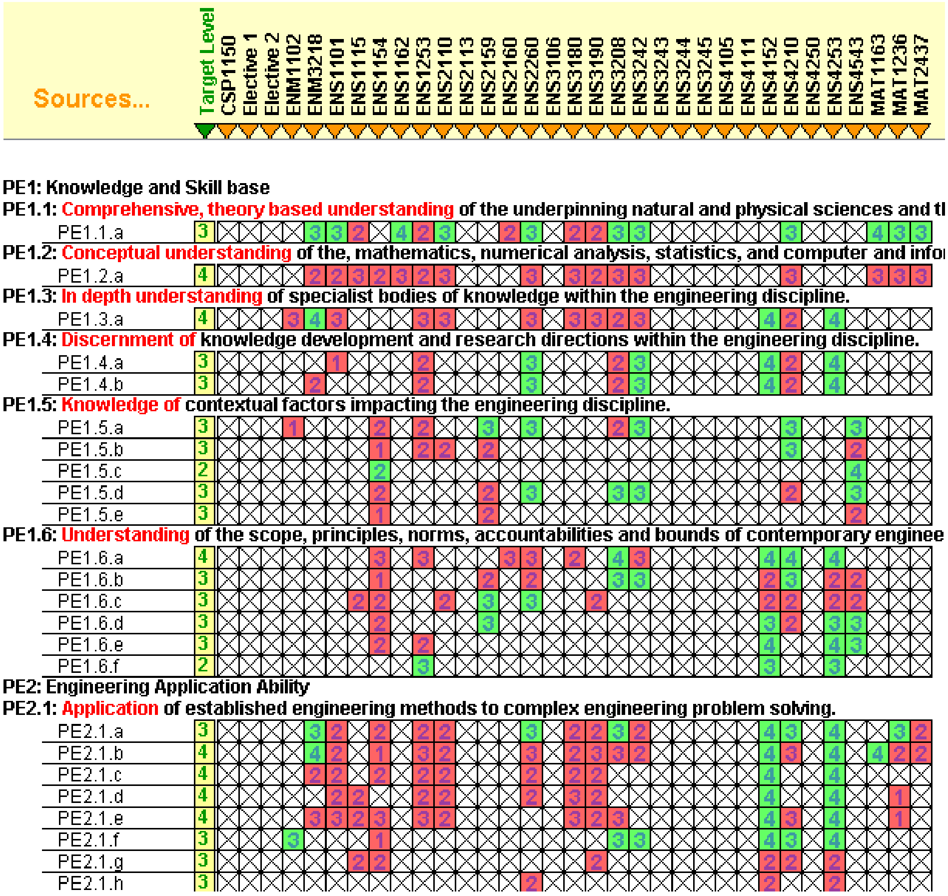

Figure 7. The Mapping Chart (part)

SUMMARY

As the interest for formal accreditation of engineering program becomes more universal there is a need for open, objective and repeatable processes that can support the task of preparing and presenting claims for accreditation from institutions (and perhaps individuals). When undertaken manually, there is a substantial effort required to build, review and analyse assessment models to meet the appropriate accreditation requirements. The methodology presented in this paper provides one approach to supporting these tasks.

The *CCmapper* modelling tool provides support for the representation of hierarchically structured competency frameworks and the capture of assessments made to set proficiency targets and to compare actual achievements against these targets. It also provides a formal structure to enable a range of auditing tasks to be facilitated to support the claims being made against the accreditation criteria.

The reporting capabilities include text reports and graphical charts. These can present concise summaries of these analyses, and in a form that can be used directly in the preparation and validation of accreditation documentation.

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