Profiling graduate outcomes for Stage 1 Professional Engineers

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***Abstract**: A study has been conducted to identify a clear set of desired target achievement levels for the Stage 1 professional competencies specified by Engineers Australia for graduate level engineers. The Stage 1 competencies provide detailed statements of required competency, but it should be acknowledged that these are not simply pass/fail achievements., Different levels of expectation can be assigned to these competencies for different levels of graduate capability and professional experience. A survey was distributed to a wide range of senior professional engineers to identify their judgements on what levels of achievement towards these competencies should be expected of a graduate engineer. These senior engineers were also asked to assess the actual competency levels they would attribute to most recently graduated engineers, using a well defined scale of achievement. While a fair degree of variation was evident, aggregation of this data set has allowed us to define a desired competency target map for the Stage 1 professional engineering competencies. Commonly perceived shortfalls in the competency achievement levels of recent graduates have also been identified. This data is very useful when looking to perform professional competency mapping at an undergraduate degree course level, both to improve graduate outcomes, and for accreditation purposes. The paper describes the survey methodology and the results obtained and represents, to the best of the authors' knowledge, one of the first attempts to formally assess the Engineers Australia competencies by practicing professional engineers.*

Introduction

Within Australia the accreditation of professional engineering courses, and persons completing these courses, is under the effective control of Engineers Australia (EA). EA is a professional organisation that is concerned with the education, training and professional development of engineering professionals in Australia. EA is also a signatory to the International Engineering Alliance (www.washingtonaccord.org) that provides international recognition in a number of countries world-wide.

In Australia, the framework for accreditation is specified by EA and all professional engineering courses are accredited. Without accreditation the graduates will not be able to be recognised as a Graduate Engineer unless they undergo an intensive personal assessment.

Bachelors, and more recently Masters, level engineering courses that are accredited by EA must satisfy the Stage 1 Competencies as specified by EA (Engineers Australia, 2006). These competencies cover a wide range of knowledge and skill areas; those considered essential for the graduate. Internationally similar frameworks exist in other countries.

While the Stage 1 Competencies provide clear statements of required competency, these are not

simply pass/fail achievements. Competencies are often defined in this simplified way, but such definitions are likely to be only applicable to relatively low level tasks. Professional Engineers require both the ability to perform a given task in a given context and also the capacity to transfer knowledge and skills to new tasks and situations, i.e. the skilled application of understanding. The competencies are therefore not just pass/fail, but will exist on a scale of achievement. One of the most common expressions of such a scale is the Bloom Taxonomy of Learning Outcomes (Bloom, 1956). There are many derivatives of this model (e.g. Krathwohl, D. R., 2002), and in particular the CDIO model that has been proposed more specifically for engineering courses (Crawley, E.F., 2001).

The CDIO model (which is derived from: Conceive, Design, Implement, Operate) proposes a five level scale of achievement as shown in Table 1. Each level of achievement is further characterised by sets of verbs and verb phrases which can be used to guide the assessment process.

Table 1 The CDIO scale of achievement.

Level	Description
1	To have experienced or been exposed to
2	To be able to participate in and contribute to
3	To be able to understand and explain
4	To be skilled in the practice or implementation of
5	To be able to lead or innovate in

In this scale a level 5 is generally accepted as referring to the capability of an experienced professional engineer, perhaps with 4 to 5 years post-graduate work experience. This scale has been adopted for this study as a means of measuring the actual and required competency levels.

The initial goals for this study were to:

1. Attempt to measure the required competency levels as specified by the EA Stage 1 Competencies for Professional Engineers on a CDIO scale of achievement.
2. Attempt to measure actual engineering graduate outcomes against these competencies, also measured on the CDIO scale.

With this information, the intention is to review the engineering courses offered in our School to:

3. Identify gaps or weaknesses in the current courses within the identified required competency profile.
4. Propose changes to these courses with the view to improving the graduate outcomes for engineering graduates.

Methodology

The EA Stage 1 Competencies (Engineers Australia, 2006) describe a hierarchically defined set of competency statements which need to be achieved in a "holistic way", specifically:

> *"It is not expected that candidates will have demonstrated every detail of the knowledge, competencies and attributes that follow; but they must demonstrate at least the substance of each element. Assessment will be made in a holistic way."*

This approach represents a reasonably pragmatic approach to what might otherwise be an exceptionally difficult task, given the scope and depth of the competency framework. None-the-less, it is this framework that we as engineering educators work within.

The primary goal of this study is thus to attempt to measure these competencies in a quantitative fashion, and the CDIO scale is used as the vehicle for this. The scale defines the required level of outcome for the graduate engineer, that is, the capabilities expected at graduation. To achieve this, a survey instrument was designed to gather informed opinions from key stakeholders on the expected achievement levels of graduate engineers across the range of competencies. This survey was derived directly from the EA Stage 1 Competencies, with each of the competency elements being extracted for assessment. The only adjustments made were that, in a few cases, competencies were disaggregated into two more simply defined elements. This was done purely to more clearly distinguish the competency statements.

Around 30 very experienced WA based Professional Engineers with expertise across a wide range of engineering discipline areas were invited to complete the survey. It is to be noted that the EA competencies are intended to be generic and apply to *all* engineering disciplines. On careful reading, it is intended that discipline-specific knowledge or skill is to be inferred in each element. While this might seem, at first glance, a weakness it does allow a generic approach to competency to be used. And this is one of the strengths of the current assessment system that is widely used across all Engineering Schools in Australia. At the end of the collection period 14 responses were received.

Results

For each of the competency elements the participants were asked to assess the level of competency on the CDIO 5-point scale. The respondents seemed to have no difficulty in completing this task. The participants were asked to make two assessments for each of the competency statements:

1. The levels of achievement ideally required from a graduate engineer as perceived by the participant.
2. The levels of achievement actually observed in graduate engineers by the participant.

Naturally, both these assessments are subjective, and it will be the aggregation of the results that will be used to infer information about the achievement profiles in a more general way.

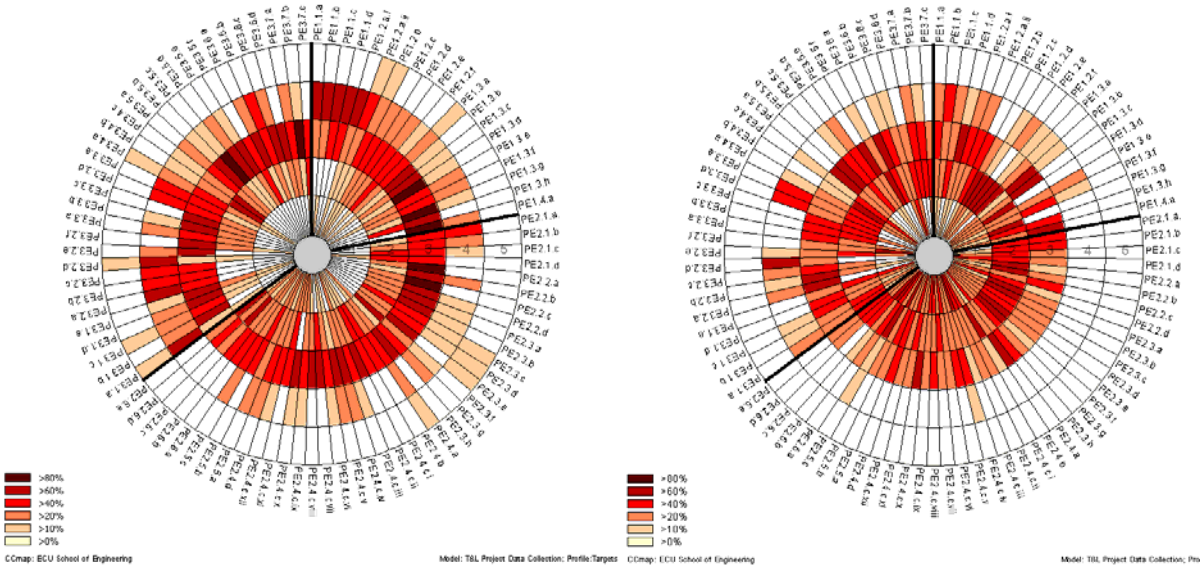
Target graduate attributes

This data captures the opinions of the respondents on their expectations of graduate engineers (i.e. recent graduates with little work experience). These expectations will be referred to as the *targets*. The raw results are shown in Figure1(a).

This figure summarises the raw data, and is interpreted as follows:

1. Each competency element is shown around the chart and matches the code descriptors in the EA Stage 1 Competency Framework (Engineers Australia, 2006).
2. The chart is a "plan" view of a large number of frequency histograms, that range over the 5 levels on the assessment scale from 1 (the innermost annulus) to 5 (the outer annulus).
3. The colour coding indicates the frequency value as shown in the legend. The darkest colour indicates that 80% or more of the respondents gave that assessed value.

To assist in visualising this chart, Figure 2 shows how a sample frequency distribution looks when extracted out of the data. There is a frequency distribution of this type for each competency element.



(a) (b)

Figure 1: Competency profile survey results a) Targets, b) Actuals

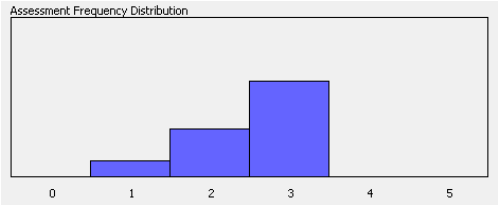


Figure 2: Sample frequency distribution for PE3.5.e (Actuals)

Figure 1(a) shows that there are a range of views expressed by the respondents, and this is not unexpected. There are a few competencies where there is substantial agreement, and others that show a wide range of assessed values. These results illustrate that the interpretation of the Stage 1 competencies onto a well formed assessment scale is not as clear cut as EA might hope. It is clear that there is some level of consensus across the respondents, but the variations are significant.

Actual graduate attributes

The respondent's assessment of actual graduate outcomes was done on the same CDIO scale and the raw results are shown in Figure 1(b). These will be referred to as the *actuals*.

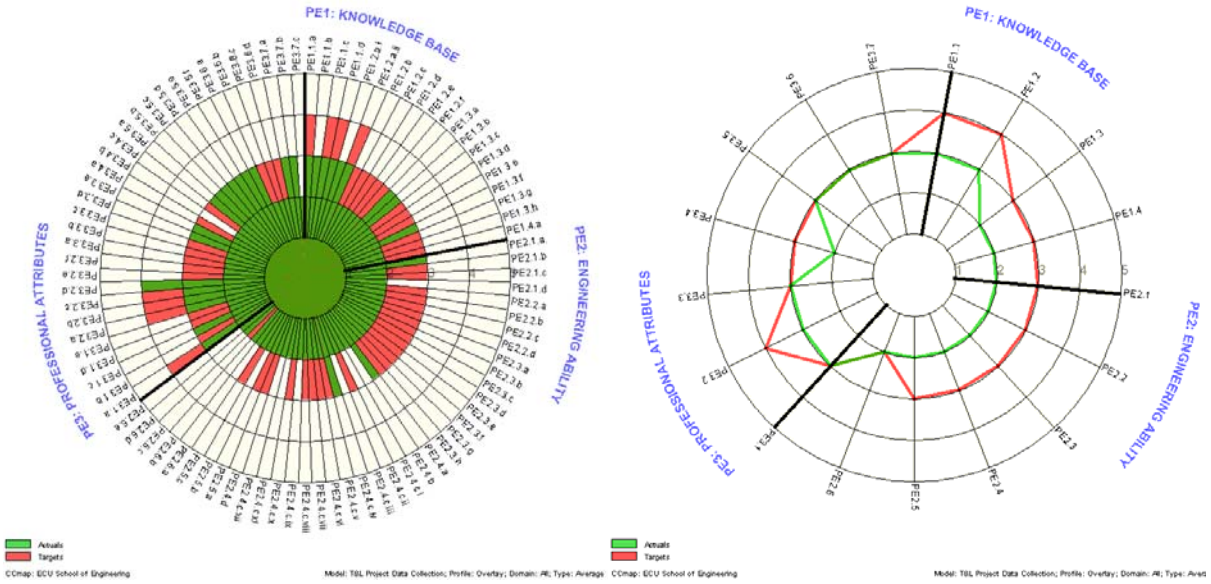
This chart should be interpreted in the same way as the previous one. In this case the assessments are made for the actual competencies of graduates as perceived by the respondents. Here we see a greater diversity of views, with less of a consensus for most competency elements. This is not unexpected given that the graduates could potentially have come from a range of different Universities and backgrounds, although all will almost certainly have graduated with EA accredited engineering degrees.

Data aggregation

The aggregation process is done by averaging the raw data, and allocating the resulting values onto the 5-point scale. The justification for this method is as follows:

1. Averaging onto a continuous scale is likely to simply "smooth out" inherent differences.
2. The discrete 5-point scale allows the removal of small variations to more clearly show differences.

After averaging the raw data across all respondents, the competency profile chart shown in Figure 3(a) can be plotted.



(a) **(b)**

Figure 3: (a) Target and actual assessment profiles (b) Aggregated to the 2nd level

This chart is interpreted as follows:

1. The red coloured chart (drawn in the background) shows the average target values as assessed by the respondents for each competency element.
2. The green coloured chart (drawn as an overlay) shows the average actual values as assessed by the respondents for each competency element.
3. The values are scaled from the centre of the chart, a level of 1 is the inner circle and a level of 5 the outer circle.

The obvious results we can see from this chart are:

1. That the actual competency levels are most often assessed at one level below the target values.
2. That there are only a few competency elements that have been (on average) assessed at level 4, and none at level 5.

Figure 3(a) includes all of the detailed competency elements. Given the complexity of the competency framework, and the concept of an "holistic" analysis it is useful to aggregate the lower level competency elements up to the second level in the framework. This type of aggregation is implied in the guidelines provided by EA and is a means of expressing a holistic outcome. The result of this is shown in Figure 3(b).

This chart gives a clearer picture of the target and actual competency profiles. The average target profile is shown by the red coloured graph, and the average actual profile by the green coloured graph. At this level of aggregation, we now see that for these competency groupings (17 at level 2):

1. There is a general agreement by the respondents that in 6 of the competency groups the actuals match the targets.
2. That for the remaining 11 groups the actual competencies are assessed as being one level below what is desired.

Conclusion

The results presented are a reflection of the views of senior practising engineers, with a range of backgrounds and roles, on engineering education in general. The key findings can be summarised as follows:

- There is an expectation that graduate engineers should achieve a level 3 on the CDIO scale for most of the competency areas (at aggregation level 2), with a few exceptions:
  a. In competency areas PE1.1: Knowledge of science and engineering fundamentals, PE1.2: In-depth technical knowledge in at least one engineering discipline, and PE3.2: Ability to manage information and documentation; a level of 4 is desired.
  b. In competency area PE2.6: Understanding of the business environment, achievement at level 2 is considered sufficient by most.
- Level 5 achievements are not expected from graduate engineers.
- Current engineering courses are not perceived to be achieving the desired level of competency in a large number of areas.

As far as the authors are aware this is the first comprehensive survey of industry perceptions of the EA Stage 1 competency standards that has been completed to date. The results of this investigation should help to inform course and curriculum development efforts designed to improve the alignment of course outcomes with industry requirements. The target profile forms a useful resource to assess existing course outcomes against in order to identify priority areas for improvement, and work is ongoing in this area.

References

Bloom, B.S. (1956), *Taxonomy of educational objectives, Handbook I: The cognitive domain.* New York: David McKay Co. Inc.

Crawley E. F. (2001), *The CDIO Syllabus: A Statement of Goals for Undergraduate Engineering Education*, Dept of Aeronautics and Astronautics, Massachusetts Institute of Technology. Accessed at http://www.cdio.org on 10th December 2010.

Engineers Australia (2006). *PO5: Stage 1 Competency Standards.* Accessed at http://www.engineersaustralia.org.au on 10th December 2010.

Krathwohl, D. R. (2002). A revision of bloom's taxonomy: An overview. *Theory into Practice*, 41 (4), 212-218.

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