Modeling Long Term Learning of Generic Skills

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Abstract. Many of the most important learning goals can only be achieved over several years. Our CUSP system helps achieve this over the 3-to-5 years of a university degree: it enables each teacher to map their own subject design to institutional learning goals; it creates both subject and degree-level models. It tackles the semantic mapping challenges using a highly flexible lightweight approach. We report its validation for 102 degrees and 1237 subject sessions. CUSP makes a contribution to understanding how to model long term learning of generic skills, using a lightweight semantic mapping based on multiple sets of externally defined learning goals. The work contributes to understanding of how to create comprehensive models of long term learning within degrees that are practical in real environments.

Keywords: Curriculum Mapping, Graduate Attributes, Accreditation Competencies, Learner Model.

1 Introduction

University degrees typically aim to build learners generic skills, such as written and spoken communication, team work and design and problem solving. These are highly valued both within learning institutions and by outside groups, notably employers. Learners need to develop these skills progressively, over several years, aided by a suitable sequence of learning experiences.

To ensure such long term learning over a whole degree, designers of each subject must appreciate how their subject fits into the full curriculum. Also, those responsible for each degree must ensure that generic skills are developed via a series of learning activities across subjects. This is quite complex, especially where students have flexibility to select elective subjects that match their background, interests and goals.

Despite the importance of learning generic skills, it is difficult to rigorously classify the skills learned in each subject. For this, we need to define two aspects: the generic skill; and the level of that skill. ITS research has typically dealt with fine grained ontological models for learning design, such as [10]. This is not adequate for our goals to model long term learning of generic skills.

A central problem is that the semantic model describing the learning progression must be agreed upon and used by several groups of people. Firstly, the lecturer responsible for teaching a particular subject must understand just what is required from their subject; otherwise they may fail to keep it true to the

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curriculum. Secondly, people at the faculty level must understand the curriculum design well enough to assess if it does develop the faculty's required generic attributes. Outside the university, accreditation bodies must be convinced that their stated learning requirements are met. Importantly, universities and accreditation bodies each define their own descriptions of generic skills.

For example, our Bachelor of Software Engineering (BSE) degree, must meet curriculum requirements defined in:

1. Engineering Australia (EA) Stage 1 Accreditation competencies,
2. Association of Computing Machinery learning objective recommendations,
3. Australian Computer Society skill recommendations and
4. University of Sydney Faculty of Engineering Graduate Attributes.

Note the different terms: skills, competencies, learning objectives, attributes. For the rest of the paper, we refer to these as *attributes*.

Another challenge comes from subject choice. Any allowed elective subjects must enable the student to achieve required attributes. Students must do them in the correct sequence, for progressive learning. So, curriculum designer must identify the attributes learned in each subject in designing a degree.

So far we have considered a single degree. A university can offer many. For example, in 2010, our university will offer over 600 degrees and over 13,000 subject sessions. Many must meet external accreditation, vocational and institutional attributes like those of the BSE.

We now describe how we have tackled this problem of modeling subjects and degrees. The next section describes related work, followed by our approach and the user view of our CUSP system. We then report its validation. We conclude with lessons learned and future work.

2 Related Work

The need for better support for designing and maintaining university degrees is recognized: as described by Mulder et. al. [8] for European standards-based design of university curricula. They report on various projects from England, Germany, France and Netherlands, noting the need for quality control, the lack of support tools for this and the challenge of multiple descriptions of the learning goals as we discussed above. McKenney et. al. [7] describe the multi-phased nature of this process and they reiterate the need for better tools to support curriculum designers.

Koper [6] explored approaches to modeling curriculum elements via a meta-model, in EML (Educational Modeling Language)[1]. With an e-Learning focus, subjects were represented as collections of reusable learning objects (LOs). It is unclear how this can scale to the degree level. While various other modeling standards (e.g. IEEE LOM, IMS LIP, SCORM, HR-XML, IMS-RDCEO) deal with parts of a whole degree, they do not help with the degree design complexity problems or multiple attribute framework semantic mapping challenges.

[1] Educational modeling Language, `http://www.learningnetworks.org/?q=EML`

Ontological approaches to such mappings have been attempted in various forms by Mizoguchi [10] (also using EML and IMS-LD), Van Assche [1], Paquette et. al. in the LORNET TELOS project [9] and others. These are promising, but cannot meet our goals. Paquette et. al. express this concern: *"what is yet to be proven is that the general approach presented here can be used at different levels by average design practitioners and learners"*. Kalz et. al. [5] also share this view: *"the design and implementation of competence ontologies is still a very complex and time-consuming task"*.

Bittencourt et. al. [2] explore use of semantic web technologies to improve curriculum quality and support the design process. They conclude, however, that *"a large-scale use of SW for education is still a futuristic vision rather than a concrete scenario"* and the implementation of ontologies is sometimes *"more an art rather than technology"*. Winter et. al. [11] also realize the strengths and limitations of traditional ITS systems with *"carefully crafted"* content and ontologies vs. e-Learning systems that are typically standards based but have *"content crafter by normal authors"*. To support lifelong learning, domain-specific ontologies will need to be mapped to each other but *"in a realistic setting...this may be difficult to do"* [11].

A limited implementation of attribute-to-subject mapping was employed by Calvo and Carroll [4] in their Curriculum Central (CC) system. It had a single attribute framework, to map a large set of subjects to these attributes. However, it could not deal with the critical external accreditation or vocational attributes, nor the complexity of elective subject choices.

Bull & Gardner [3] mapped multiple choice questions, in several subjects, to UK SPEC Standards for Professional Engineering attributes (UK-SpecIAL). As students complete online questions, the system builds open learner models, enabling students to see their learning progress, and which subjects could provide the missing attributes. This gave students a valuable big-picture view. However, the system lacks the generality we need, i.e. mapping across all forms of learning activities and assessments and supporting multiple sets of learning attributes.

3 Approach

Our approach is to create lightweight, two part models, based on *attribute definitions* and *level definitions*. These support models with the semantic relationships between any sets of attributes. We took this approach for modeling generic skills, due to the generality of their *attribute definitions* with the *level definitions* being sub-concepts that are also broad. This approach seemed promising for our multiple goals, notably the pragmatics of meeting the needs of teaching staff, institutions and accreditation.

Taking the institutional goals as the *base model*, we establish a set of *attribute definitions* from the established set of graduate attributes. This is an important decision: we consider the foundation should come from the institution's own goals. In our case, this has just 7 top-level attributes, most covering generic skills. For example, *Design and Problem Solving Skills*, one of the 7 top-level attributes, is defined as the *Ability to work both creatively and systematically in developing effective, sustainable solutions to complex practical problems.*

To model progression in learning, we assigned 4 or 5 *level definitions* for each attribute. This gives a coarse set of levels for key stakeholders to agree on, both for the levels and for classifying learning activities. This granularity is meaningful to model progression over the 3 to 5 years of a degree.

To incorporate other attribute frameworks into the *base model*, the curriculum designer maps their attributes against the *base model attribute definitions* and *level definitions*. So, for example, the EA Accreditation Competency statement *"experience in personally conducting a major design exercise to achieve a substantial engineering outcome to professional standards'* maps to our faculty *Design and Problem Solving Skills* attribute at *Level 3*. Additional frameworks can be systematically incorporated into the model by repeating this process. This means that *subject lecturers* map their subject assessments and learning activities to the institutional *base model*. They can ignore other attributes sets, minimizing demands on them. A big-picture view of a degree can be extracted from the model for any of the attribute frameworks, simply by resolving the semantic relationships.

4 CUSP User View

CUSP[2] implements this approach, with interfaces to manage the modeling processes. Figure 1 illustrates part of the *base model*, with the two level hierarchy of *attribute definitions* such as *Fundamentals of Science and Engineering* and an associated *level definition*, expanded in the figure. It aims to avoid restrictions on the structure of an attribute set. Attributes can be arbitrarily nested, or flat. Each attribute can be given a code, a label and a description and it can have any number of levels, each with their own descriptions. Clicking the yellow 'E' control next to an attribute or level brings up the floating Equivalence editor (bottom-right of Figure 1). This enables *curriculum designers* to define many-to-many semantic relationships between attributes or levels from different sets. The mappings are accessible and editable from either side.

We now describe the lecturer view for individual subjects. A lecturer can define a high level subject outline with information such as a handbook description, prerequisite/prohibition subject requirements, teaching methods & activities, learning outcomes, assessment tasks, resources and scheduling information. The fields are on the tabs for easy navigation as shown in Figure 2.

This shows a set of 5 attributes from our Faculty of Engineering Graduate Attribute Framework. Each maps to a specific level (clicking the attribute brings up full textual descriptions). The lecturer provides a free-form description stating how the attribute is supported by the subject. The subject attributes are further mapped (by lecturers) to learning outcomes and indirectly to assessments (each assessment can be mapped to one or more weighted learning outcomes).

On the degree side, a degree coordinator links a degree to any number of attribute frameworks. Our Bachelor of Software Engineering degree links to the

[2] Course & Unit of Study Portal - *course* being a degree and *unit of study* a subject.

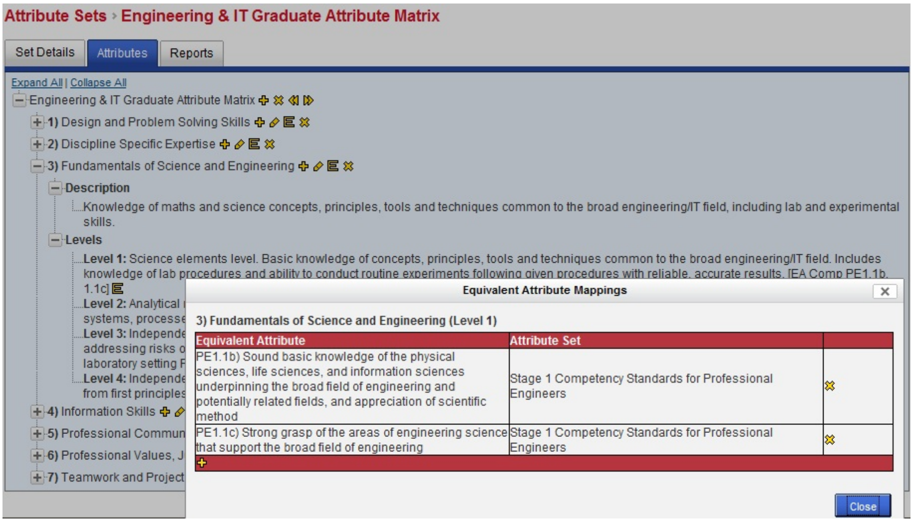

Fig. 1. Example of attributes from Faculty of Engineering Graduate Attribute Framework, with floating equivalent editor bottom-right

Fig. 2. Attributes linked to a subject and described by lecturers via development methods

Faculty of Engineering Attribute Framework and the EA Accreditation Stage 1 Competency Standards. The degree structure is then defined in terms of core and elective subjects, streams and recommended elective blocks.

We now have multiple attribute frameworks captured in the system, as well as the semantic relationships between attributes and levels, the mappings of attributes to subjects, learning activities and assessments, and the degree core/elective subject structures. These are all the pieces we need to start building our big-picture view of full 3-to-5 year degrees.

Figure 3 shows our Bachelor of Software Engineering degree in terms of the Faculty of Engineering Attribute Framework. The left column of the matrix has 7 top-level attributes and along the top are columns for each level defined.

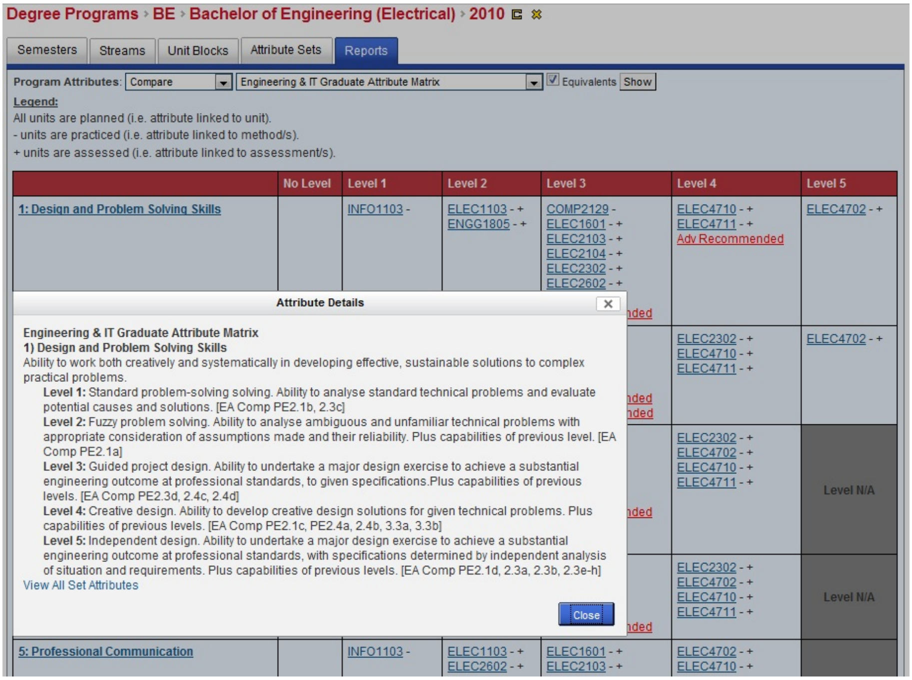

Fig. 3. Overview of the BSE degree in terms of planned, practiced and assessed attributes

Clicking an attribute in the left column brings up the full descriptive text for reference. In the cells of the matrix lists of subjects that develop the attribute at the corresponding level. The plus/minus markers next to each subject code differentiate between planned, practiced and assessed[3] attributes. The red *Adv. Recommended* subject label in *Design and Problem Solving Skills, Level 4* represents a subject recommended elective block (the placement of this block in the matrix is based on a CP threshold formula). The two drop-down boxes at the top allow the selection between different report types and, importantly, between the different attribute frameworks linked to the degree.

Switching to the EA Accreditation attribute framework regenerates the report as shown Figure 4. We now see the EA Accreditation competencies along the left column and the relevant subject codes in the right column. The EA attributes do not have any levels and hence no additional cells to the right. The list is easily scrollable however and an accreditation review panel could easily look at this to see which subjects support each attribute and if there are any knowledge gaps. Clicking on the subject takes the user to the full outline describing the precise attribute mappings. Notice that this report is generated by exercising our semantic equivalence mappings. We could easily map additional attribute frameworks to our BSE degree and generate similar reports.

[3] Here planned means material is in the curriculum but there are no linked learning activities or assessments, practiced means there are activities but no assessments.

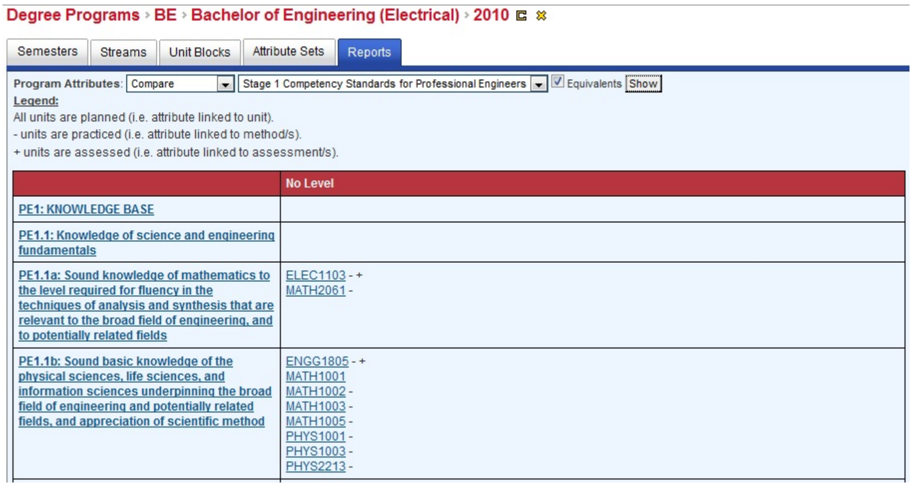

Fig. 4. Switch to the EA Stage 1 Accreditation Competency Framework

The chart visualization in Figure 5 is another big-picture view of our BSE degree. Along the x-axis we have the 7 faculty attributes. Along the y-axis we have the percentage distribution of each attribute in terms of assessments. That is, the BSE degree devotes roughly 22% of all assessment tasks to *Design and Problem Solving Skills*. Each column is further broken down into the corresponding attribute levels, which are color-coded. A mouse-over reveals the precise percentage distribution of each level.

5 Validation

The CUSP system has been deployed to three Faculties, namely Engineering, Architecture, Design and Planning, and Health Sciences. It has been populated with 8 generic attribute sets, 278 individual attributes, 102 degrees, 886 subjects, 1237 subject sessions, 3849 learning outcomes and 2418 assessment items. Altogether 2189 of the 2418 assessment items have been mapped to specific subject learning outcomes which were in turn aligned to the relevant generic attributes for the subject. The capture of outcomes, assessments and graduate attribute relationships has relied upon a combination of lecturer and administrative staff input. Outcome and assessment mappings have been reviewed and adjusted by degree coordinators or other experienced staff wherever possible. Quality of mappings varies widely from subject to subject and degree to degree but the data has been sufficient to begin generating some quality review reports through the system itself.

We conducted a test to validate the equivalence mapping approach as described in Section 4. To make this test more effective we performed it on two very different professionally accredited degrees: a 2-year Masters degree and a 4-year Bachelor degree; each in a different faculty. Subjects for each degree were

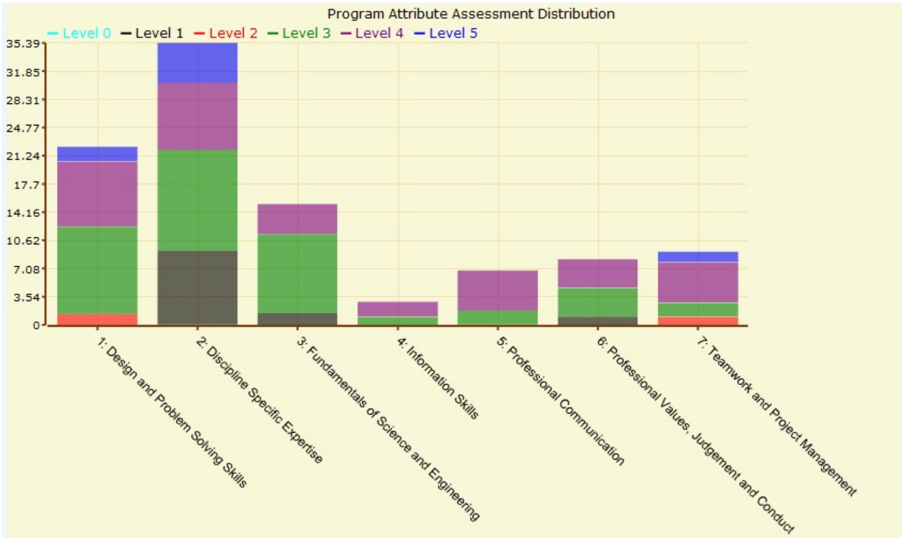

Fig. 5. A stacked column chart showing percentage distribution of assessed faculty attributes

mapped against the relevant faculty's primary attribute framework, which was in turn mapped, via equivalence relationships, to a second framework comprised of competency standards required for accreditation.

A report compiling subject learning outcomes under accreditation competency headings was generated for each degree. A recent graduate of each degree was asked to examine each outcome and determine in each case whether it represented a meaningful contribution to the competency descriptor under which it appeared. In cases where the match was not confirmed, the learning outcome mapping to the faculty graduate attribute framework was checked, by a curriculum expert, to determine whether the failure came from original data entry (learning outcome mapped to incorrect generic attribute/level), or from an equivalence mapping error (learning outcome mapped to correct generic attribute/level, but accreditation competency equivalence mapped to incorrect generic attribute level), or an attribute translation error (learning outcome mapped to correct generic attribute/level with correct equivalence mapping, but mismatch with learning outcome). All three failure types were found, as shown in Table 1 below.

The Masters degree had a high match ratio between learning outcomes and equivalence attribute mappings (92.28%), with only 4.56% of mismatches due to attribute translation errors (i.e. loss of context in cross-mapping more granular accreditation competencies to more generic faculty attributes, which are then mapped to more granular subject learning outcomes). The Bachelor degree did not fair as well with only a 49.63% match ratio between learning outcomes and accreditation attributes. The primary cause of this low ratio was due to incorrect

Table 1. Learning Outcomes matching accreditation competency descriptors as resolved via attribute equivalence mappings for two professional degrees

	Masters	%	Bachelor	%
Learning outcome mapping relationships	285		544	
Relationships confirmed	263	92.28	270	49.63
Relationships not confirmed	22	7.72	274	50.37
Failure at learning outcome source	8	2.82	208	38.24
Error in equivalence settings	1	0.35	27	4.96
Attribute grouping hard to translate	13	4.56	38	6.99

mappings between learning outcomes and the core faculty attribute framework. The attribute translation failure rate was only 6.99%. This degree, related subjects and core faculty attribute mappings were imported from an earlier system which had no accreditation competency equivalences defined, whereas the Masters was a newly created degree and hence had more accurate data.

This validation exercise shows our light-weight approach does not provide perfect mappings between degree subjects and multiple attribute frameworks. Equivalence translation errors sometimes appear due to the multi-level mapping of attributes at different granularities. The mappings are, however, valid to a large extent when data is correctly entered. High mismatches can be identified via the reporting tools which signal the need for further evaluation to determine the source of failure, which is valuable for long term degree quality control.

6 Conclusions and Future Work

We have described our approach to support design of flexible degrees that are accountable in terms of ensuring that important generic skills and accreditation requirements are met over the full 3-to-5 year duration. We have implemented this in CUSP and reported its use to map multiple attribute frameworks to individual degrees, and map attributes to each core or elective subject that is part of a degree. The CUSP reporting tools give lecturers and degree coordinators a big picture view of entire degrees. This helps identify knowledge gaps, accreditation requirement gaps, and progressive learning inconsistencies.

We have validated our approach by deploying the system on a large scale in a live university environment with real data. The system is in active use with 102 degrees, 1237 subject sessions and 8 different attribute frameworks. From the evidence of Table 1, the equivalence mapping tool is certainly not a mechanism for eliminating all errors or weakness in curriculum design and documentation but rather tends to amplify the impact of any errors present. In doing so, it provides a sensitive test of quality in all the elements concerned.

While CUSP has demonstrated the value of our approach for curriculum designers, at the level of the subject and the degree, we plan to extend our approach to incorporate available assessment data within each subject to create detailed individual student models. To do this, we will move beyond our current mapping of attributes to assessments via learning outcomes. This will allow us to explore the value of personalized attribute progress matrices for students in terms of making more informed subject enrollment decisions, personal reflection and gaining a better understanding of the governing factors influencing their degree. It will also provide a basis for longitudinal data mining of the learner models to improve understanding of the causes of student difficulties.

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