Largescale, long-term learner models supporting flexible curriculum definition

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Abstract

Taking a view of curriculum design as the definition of a long-term learner model, we are exploring ways to capture the complex set of goals for tertiary institutions, their faculties, staff and students as well as accreditation requirements. This can serve several important goals: greater flexibility for students; providing academic staff with greater understanding and control of the curriculum; improved quality control at the level of school, faculty, university and more efficiency and effectiveness in accreditation procedures. This requires several ontologies: the graduate competencies and generic skills, the accreditation types and, the teaching methods. It also requires excellent user interfaces (UIs) for staff to maintain these. The paper describes the broad vision and reports experiences on the current implementation, particularly its value in ensuring for institutional and professional goals for generic skills as well as and its limitations especially in terms of scalability to the institutional level.

1 Introduction

Rapid advances in science, technology and related fields, coupled with the growing number of specialised disciplines has resulted in complex tertiary education curricula design requirements. A typical University curriculum must satisfy numerous regional, professional and institutional requirements and recommendations in the form of generic attributes, professional skills and accreditation competencies. Designing a full three-to-five year degree programme that satisfies all of these curriculum requirements is a challenging task.

Further, we will show that designing and maintaining a large collection of cross-discipline degree programmes, administered by different departments, is a complex scalability problem. Namely, each curriculum may have been designed with different sets of degree requirements, with semantically similar skill or competency statements expressed in different words. Prior research has explored approaches to either standardising competency statements [1], [2], [6], [5] and rewriting the statements to formulate higher-level competency ontologies [3], [8], [7]. These approaches are not feasible in large institutional environments where the competency sets come from many different sources and are expressed in many different formats.

1.1 Terminology

It is important to establish the core learning terms we will use:

1. *Curriculum* - the subjects comprising a course of study in a school or college.[1] Synonyms include *degree* and *degree programme*.
2. *Syllabus* - the topics in a course of study or teaching, especially for an examination.[1] Whilst a curriculum or degree is a collection of subjects, a syllabus is a collection of the topic and outcome requirements for the curriculum. Synonyms include *degree requirements* and *curriculum requirements*.
3. *Subject* - a branch of knowledge studied or taught.[1] In this context, subject will be used in the classical sense of describing a University/College Unit-of-Study that a student may be enrolled in, such as MATH1001, Introductory Physics, Micro Economics, etc. Synonyms include *Unit-of-Study*, *unit* and *course*.
4. *Competency* - any form of knowledge, skill, attitude, ability or learning outcome that can be described in a context of learning, education or training [3]. Synonyms include *Attributes* and *Skills*.
5. *Faculty* - a group of university departments concerned with a major division of knowledge.[1] Synonyms include *School* and *department*.
6. *University* - a high-level educational institution in which students study for degrees and academic research is done.[1] Synonyms include *college*, *educational institution* and *institution*.

[1]Online Oxford Dictionary, `http://www.askoxford.com/`

1.2 Significance and Motivations

Challenges in meeting complex curriculum requirements is increasing in significance as accreditation processes become more stringent, as global economies converge and as the global marketplace expands. We envisage that defining a long term learner model for each professional qualification, and mapping all the subjects and their component learning goals, activities and assessments to this, has the potential to play an important role in addressing these accreditation needs at the same time as improving the internal management of the curriculum for all stakeholders, including the students, academic staff and faculties.

The complexity and interactions in degree structures makes for high workloads for accreditation. Students are affected when their particular subject choice means they cannot graduate with their desired majors. Students may also be unfairly prevented from enrolling in subjects of interest when those are not listed in the curriculum programme, even though they could satisfy all the degree requirements. This is especially common in interdisciplinary, combined degrees such as Engineering combined with Law, Economics or Computer Science.

Our primary motivations are to define a set of learner models for each degree programme, so that it can:

1. Assist designers of *degree programmes* to gain and maintain a big-picture view of the full set of competencies developed through the programme. For example, to see that communication skills are developed in three first-year subjects but only one second-year subject.
2. Assist designers of a *subject* to ensure it is consistent with the big-picture defined in 1.
3. Improve the *long term quality* of degree programmes as the professor for a particular subject can see how skills in that subject are needed for the big-picture in 1.
4. Make it easy to demonstrate to an *accreditation* body that a degree programme meets their requirements.
5. Support the long term vision of *fine grained model* of each learner's developing competency knowledge.
6. Enable *learners to understand* why aspects of one subject are there as part of the big picture of 1 and so appreciate why they should learn these.
7. Support greater *flexibility for students* in substituting subjects of interest but still meeting degree goals;
8. Facilitate *institutional data mining*, for example to identify at-risk students, comparing measured achievements against curriculum, identifying which subjects are predictive of overall student success, restructuring degree programmes based on competency gap analysis, etc.
9. Provide learners with a *portfolio* to demonstrate their competencies to employers, accreditation/certification bodies and/or other learning institutions.

1.3 Goal vs. Actual Learner Model View

One way to represent a curriculum is to consider the different sets of degree requirements binding a curriculum design as sets of goal Learner Models (LMs). So, one curriculum may have an *accreditation competency goal LM*, another *University graduate-attribute LM*, yet another *Faculty graduate-attribute LM*, and a *vocational goal LM*. Subjects within the curriculum can then be viewed as the means to enable a student to build their actual Learner Model to include all these goals, at the required levels.

Figure 1 illustrates this. On the left are the models associated with a Career X, such as Software Engineering. To qualify as a Software Engineer, a person must acquire accreditation, institutional, and vocational target competencies & skills, shown as goal LM sets. On the right, we show a Person Z, who wants to become a Software Engineer. To do so, they must acquire an actual Learner Model meeting all goal LMs. They do this by enrolling in Curriculum Y, designed to prepare Software Engineers, but allowed some flexibility in the choice of subjects. Each subject develops a subset of goal competencies, as indicated in the middle set of LMs. In the figure, Person Z has not yet developed skills D, E and III as they have not been covered by any subjects studied so far.

The figure illustrates the relationships between goal LM competencies (left), curriculum subjects (middle) and actual acquired LM competencies (right). Creating a system which makes it easy to define such LMs and provide effective interfaces for each of the people involved in the teaching and learning processes can provide a foundation for achieving our goals described above. So, for example, an accreditation panel can assess if Curriculum Y is adequate, by comparing the accreditation goal LMs against the degree's subject LMs. Learners could seek accreditation based on the comparison of their actual LM against the accreditation goal LM. Curriculum designers could view the definition of the degree subject lists as the task of ensuring that the LM for each student who completes the required subjects will have a LM that covers all elements of the various goal LMs. Academic staff, when designing their own subject would be able to see the relevance of all assessment tasks and teaching methods towards enabling students to acquire the goal LMs. The student would be able to identify the gaps in their LM and proactively seek out the missing skills. A student would also be able to make more informed subject choice decisions based on competency requirements, their own learner model and actual interests.

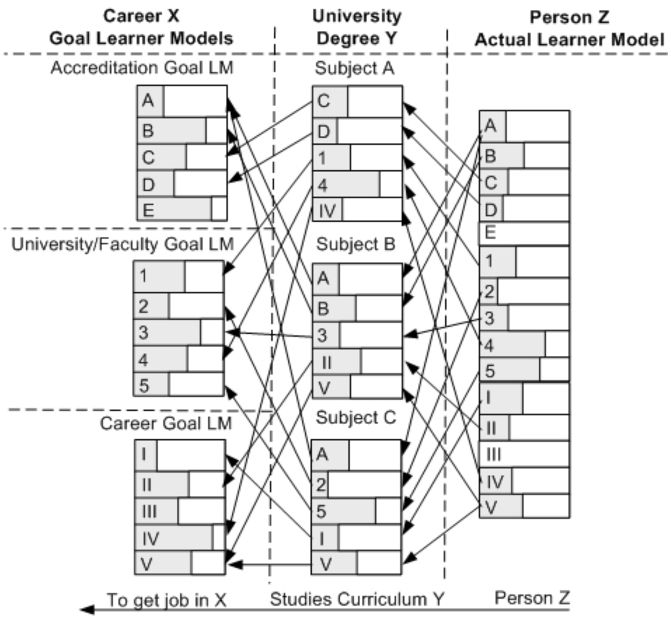

Figure 1: Goal vs. Actual Learner Models

1.4 Semantic Relationships Scalability Problem

The example above concerns a single learner, enrolled in a single curriculum, targeting a single career path. We now consider the larger scale issues of modeling many learners enrolled across many degrees, composed of subjects shared across degrees and serving many goal learner model sets.

Figure 2 illustrates the highly-interrelated nature of curriculum competency requirements, subjects and subject elements (learning outcomes, teaching methods, assessments). It shows three degree programmes on the left, D(A)-D(C), each with its own set of generic and professional attributes and accreditation competency requirements (goal LMs). Arrows indicate the relationships between skill requirements, both within and across degrees. At the right, we show the same three degree programmes, this time as compositions of core, elective and free subjects (which typically build generic skills). In the middle, we show a student enrolled in degree C, doing subjects U(A)..U(C). Each subject has a set of learning outcomes, teaching methods and assessments which directly link to degree requirements.

Our goal is to capture these complex interleaved relationships explicitly, reducing brittleness in degree programme designs. When a professor takes on a new subject, or decides to alter an existing one, they need to appreciate how much flexibility they have in revising the learning objectives, changing the teaching methods and altering assessment tasks. For example, dropping a group presentation from the subject may indirectly drop the teamwork, leadership and communication attributes that the curriculum needs to have developed in the subject, potentially impacting all degree programmes sharing this subject and relying on it to satisfy the degree requirements. At worst, this can mean that a student may no longer qualify to graduate, or a curriculum may no longer pass accreditation.

Curriculum competency requirements come in many different (but semantically related) textual statements. As an example, our Electrical Engineering Degree must satisfy University Generic Graduate Attributes, Faculty professional Graduate Attributes, as well as competency requirements of Engineering Australia as part of the Stage 1 Accreditation Checklist.

A Computer Science degree would also have to satisfy the same University Generic Graduate Attributes, and a separate set of professional Graduate Attribute requirements defined by the Faculty of Science and School of IT. This degree requires additional competencies and generic skills defined by the Australian Computer Society (ACS) and the Association for Computer Machinery (ACM).

Similarly, other degrees from other faculties and in different domains of study have vastly different sets of semantically related internal and external competency requirements (refer to Appendix A for some examples). This makes it difficult to capture and map these requirements to each subject and subject element consistently. This results in each Faculty or School all tackling the mapping problem from their unique perspective and with their unique set of requirements and inputs as their primary design drivers. So, each Faculty creates their own spreadsheets listing degree requirements, and creates a listing of subjects mapped against the syllabus requirements. Some Faculties and Schools go further, linking individual subject elements to the curriculum requirements

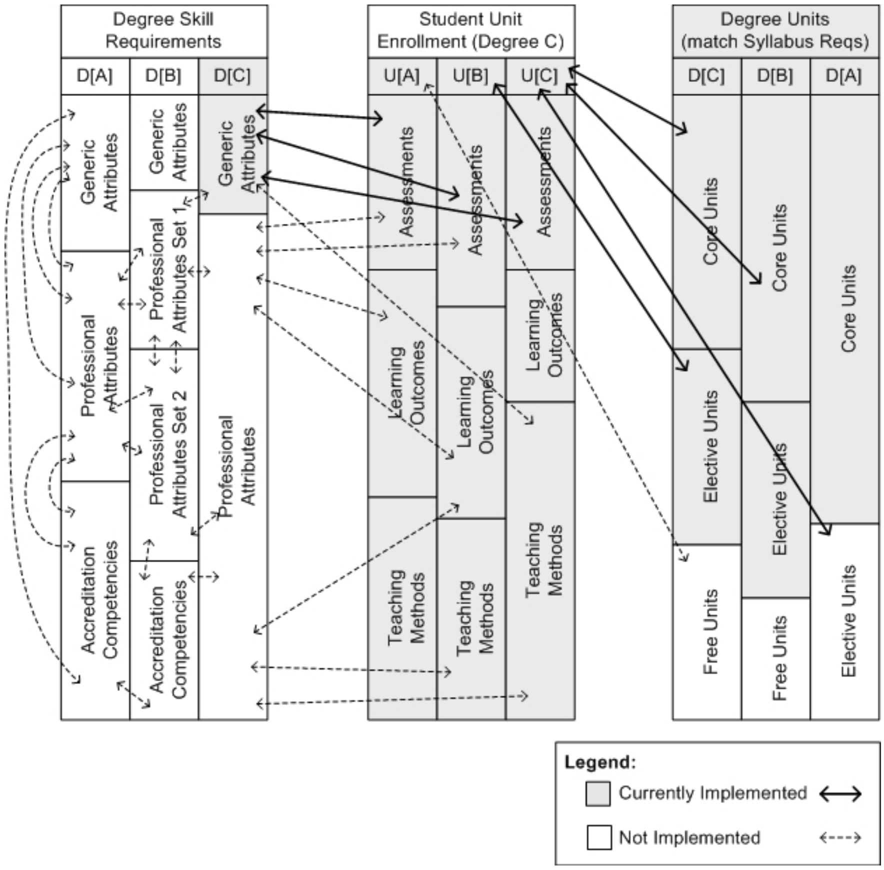

Figure 2: Curriculum Relationships in Current vs. Proposed System

in custom-built relational systems.

Such solutions may partially work within a single Faculty or School. However, they do no scale when subjects are reused as parts of many different degrees in different disciplines, as is common. To address this, we are exploring a more systematic approach, capturing all curriculum competency/skill requirements, all mappings between different sets of requirements and mappings between subject elements (learning-outcomes, assessments, teaching-methods) and competency/skill and also representing relationships between them.

2 Related Work

2.1 International Attempts at Curriculum Requirement Standardisations

M. Mulder et al. analysed the trend towards competency-based development of curricula in European nations [6]. He explains the intentions of the ECVET (European Credit System for VET) and the ECTS (European Credit Transfer System in Higher Education) to describe learning outcomes as topologies of knowledge, skills and competencies based on varying terminologies through the Tuning Educational Structures in Europe project, which "proposes programs based on learning outcomes [that] are described in terms of subject specific and generic competencies, [where] competencies serve as reference points for the design of curricula and evaluation in order to make study programs comparable." The Tuning Project is explored in greater detail further down.

Mulder et al. also discuss the UK National Vocational Qualifications (NVQs) and the controversy as to whether or not they are a good measure of a person's skills or suitability for a particular job. The controversy stems from the fact that the NVQs are described in terms of outcomes, demonstrations and assessments, which contradicts (or only partially supports) some of the many different theoretical definitions of competencies.

Furthermore, Mulder notes that "in June 2002, the Federal Ministry of Education and Research [in Germany] decided to establish national standards of education [but] it remains unclear how these standards can be realized and assessed.". Likewise in Netherlands, "although many institutions claim to have a competence-based curriculum, there is a lot of window-dressing going on, in various cases only superficial changes have taken place and learning processes have not changed". In other words the competencies are not being systematically tracked to curricula elements.

Mulder concludes by saying that the competency concept in educational curricula is not new, but the broad definitions of what a competency actually means are widely varying, and attempts at standardisation of competencies or implementations of national vocational competency frameworks thus far have been met with heavy criticism in most countries due to these differences of opinion.

The analysis and critiques however highlight the growing desire for standardised vocational competency sets as a means of qualifying educational curricula, even if the terms cannot be agreed upon. Also hinted at is the need for flexibility in the treatment of such competencies, not only at national or state levels but also at professional and institutional levels, whilst the international standards are still being refined and developed. These points are further reinforced by [5].

The Tuning Educational Structures in Europe Project [2] was born from political desires to create an integrated higher education programme to support compatible and comparable education qualifications in a converging economy (see Bologna Declaration [1]). The Tuning framework defines the combination of generic and subject-specific competencies as the fundamental elements required for specifying and understanding any curricula, where a curriculum is typically composed of learning outcomes, teaching methods, workloads and assessments that are supersets of the fundamental competencies.

The Tuning Phase 1 Report [2] states "Competences are normally obtained during different course subjects and can therefore not be linked to one subject. It is however very important to identify which subjects teach the various competences in order to ensure that these are actually assessed and quality standards are met. It goes without saying that competences and learning outcomes should correspond to the final qualifications of a learning programme". A list of generic/professional competencies and learning outcomes, grouped by different subject area, has been collaboratively compiled by over 135 European Universities spanning 27 European countries and is included in the report. However, it is important to note that whilst Tuning is attempting at creating a standardised set of generic skills and competencies, many degree programmes will still need to satisfy curriculum requirements defined by numerous other bodies.

2.2 Implementation Techniques and Technologies

Whilst Tuning provides the curricula design methodology of interlinking learning outcomes, teaching methods, workloads and assessments to generic and specific competencies, it does not provide significant technical guidance on how to systematically implement this framework, especially in complex scenarios such as when a student may wish to change curricula streams half-way through a programme. This process is complicated by the fact that semantically similar competencies governing the two streams are likely to be described in different linguistic terminologies, and likewise for the learning outcomes and other subjects elements.

The technology implementation shortcomings of the Tuning project are partially addressed by [4]. Koper attempts to bring together low-level learning objects into meaningful correlated sets forming subjects via EML (Educational Modeling Language). He defines a high-level UML architecture and a DTD implementation schema for modeling subjects as compositions of interrelated elements from domain models, educational theories, competency based learning objectives, pedagogical methods and so forth. The EML notation proposed appears capable of modeling some of the requirements in our problem definition, and potentially extensible to meet the remaining needs, as well as providing the needed interoperability and portability for the defined system.

Not mentioned in the paper however is how an EML-centric system will scale when considering hundreds of curricula composed of thousands of subjects and hundreds of different domain models, attribute lists, accreditation competency requirements and professional/vocational guidelines. That is, how should all these sets of information be modeled and handled? How should they be presented to the users? Can the relationships between curricula requirements and subject elements be easily maintained? What considerations need to be given in constructing maintainable front-end implementations? Is manual relating of competencies in large sets even feasible? Would natural language processing techniques based on domain ontologies or generic word taxonomies be useful in automating the creation and maintenance of the complex relationships?

EML is no longer being developed and has been mainly incorporated into IMS-LD.[2]

2.2.1 Ontologies of Competencies

Mizoguchi [9] proposes using an ontology of educational theories represented using EML and IMS-LD for integration with LKMS (Learning and Knowledge Management Systems) and LD (Learning Design) systems, assisting authors to construct learning activities based on knowledge of the underlying domain concepts. The underlying

[2] http://www.learningnetworks.org/?q=EML

domain concepts (i.e. competencies) are interrelated via 'is-a', 'part-of' and 'participates-in' mappings. The techniques introduced in this paper could be used to build ontologies of fine-grained accreditation competencies for specific curricula, which would then be used to create the initial subjects by formulating related learning outcomes, selecting from lists of teaching methods, creating relevant assessment tasks and linking these with competencies from the domain ontology. The domain competency ontologies may then be extended to capture relationships between cross-domain competency sets defined in different linguistic terminologies.

This would solve the Tuning problem of the complex scenario where a student changes degree streams and wishes to transfer gained competencies to a new context. The problem with this approach however is the number of ontologies required for defining the competency requirements of each domain and the additional ontologies needed for capturing the relationships between cross-domain competencies, and between competencies and learning outcomes, teaching methods, assessments, etc. Implementing an ontology-centric solution may introduce significant design and maintenance overheads in this regard and may not be suitable from a curriculum design end-user perspective (i.e. the user responsible for creating a subject outline would also need to traverse the ontologies and link to the correct nodes, etc).

Van Assche tackles the problem of retrieving relevant LOs for a particular curriculum programme based on the syllabus competency requirements in [3]. Assche decomposes curriculum learning outcomes and learning objectives into simple [action-verb, topic] competency tuples defined against fixed taxonomies. Using this approach, the mappings between competencies can be inferred based on the underlying taxonomy relations and thus tagging an LO against one competency specific to one curriculum would be equivalent to tagging the LO against all related competencies in other curricula. This automated competency mapping technique could be applied to the example scenario introduced in section 1.4, however it is rather limiting in that each competency needs to be re-written against the pre-defined taxonomies. This may not always be possible given the broad definition of a competency and number of curriculum competency requirement sets. Rewriting/decomposing the curriculum requirements would also require additional mappings back to the original definitions for automated accreditation reporting, etc. Not explored in the solution is how a generic taxonomy such as WordNet[3] would compare against the custom domain taxonomies developed in terms of relevance of relational inferences.

The work conducted by Paquette and others on the LORNET TELOS project is also of strong relevance to our research goals. Paquette [7] describes the need for competencies as the driving force for future educational instructional curricula and provides a set of ontologies to support the definition of a competency as "the statement of a relationship between a generic skill applied to knowledge at a certain degree of performance". Namely, a domain competency ontology is used in conjunction with a generic skill sub-ontology to describe deep concept relationships. The theoretical techniques are then (partially) integrated into the TELOS framework which provides the editors and screens necessary for constructing and administering these ontologies.

Whilst this appears to be a very comprehensive solution, its weakness is the complexity required for constructing and maintaining the ontology models. An early implementation case-study referenced in the paper suggests the domain ontology was iteratively constructed and refined with the on-going contributions of numerous domain experts over an extended period of time. Likewise, the paper concludes by saying "the major challenge is to integrate them [the ontology tools] in a coherent, flexible, user-friendly, and scalable way, within the new context provided by the semantic web and the ontology-driven architecture of TELOS" and also "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."

This reinforces the perceived problem with manual domain ontology construction based solutions, that is, the editing process is overly dependent on end-user expertise and collaboration. Given that curriculum requirements come from many distributed sources, it would prove difficult to expect academic staff to take each requirement set, published in different formats and with different terminologies, and transform these into complex, comprehensive ontologies that accurately capture the semantic relationships.

2.2.2 Learning Standards

Mizoguchi, Koper and Van Assche all make mention of some of the more major learning standard families such as IEEE LOM[4], IMS LIP[5], SCORM[6], Dublin Core[7] and the numerous specifications therein. Whilst these stan-

[3] http://www.iversonlang.com/

[4] 1484.12.1 IEEE Standard For Learning Object Metadata, IEEE Learning Technology Standards Committee, http://ltsc.ieee.org/wg12/files/LOM_1484_12_1_v1_Final_Draft.pdf

[5] IMS Learner Information Packaging Information Model Specification, IMS Global Learning Consortium, Inc., http://www.imsglobal.org/profiles/lipinfo01.html

[6] Sharable Content Object Reference Model, Advanced Distributed Learning, http://www.adlnet.gov/Technologies/scorm/SCORMSDocuments/SCORM\%20Resources/Resources.aspx

[7] Dublin Core Metadata Element Set, Dublin Core Metadata Initiative, http://dublincore.org/documents/2008/01/14/dces/

dards may add value in trying to solve different parts of the problem (HR-XML[8], IMS-RDCEO[9] and more recent descendants give significant treatment to the standardised representation of competencies for example), they do not provide an integrated approach for modeling complex curricula, representing the complex competency-subject relationships, and constructing scalable, maintainable systems to make these work in a real-life educational environment.

3 Current Implementation - Scalability Issues Across Disciplines

Our Engineering Faculty has created a system which achieves some of our goals, outlined in Section 1. It is an OpenACS web-based application in which academics construct subject outlines with their learning outcomes, teaching methods and assessment methods, linking these sub-elements to Faculty graduate attributes. Figure 2 indicates aspects implemented in this system as shaded blocks.

The system has been in use for three years. However, we now face scalability challenges. Importantly, it only caters for Professional Graduate Attributes of one faculty, Engineering, and has no support for University Generic Attributes or Engineering specific accreditation competencies. These are needed even for Engineering graduates, to track whether a set curriculum ensures that students acquire all the University requirements, and critically, whether achieve requirements for engineering accreditation. In terms of Figure 2, the current system only implements one Professional Attribute set for one Faculty or School and is missing the generality required for implementing the remaining degree programme requirements and relationships.

Additionally, there is a real need to make these facilities available more broadly, across more Schools and Faculties. This is impossible because each Faculty has its own set of graduate attributes, linking to University generic attributes differently. Furthermore, while some Faculties do not need to take account of accreditation requirements, many curricula are based on external professional syllabus recommendations, such as the Australian Computer Society and Association for Computer Machinery.

Another challenge for the current system related to load on academics who currently enter all the information for the subjects they teach. As the current system does not serve the goals we have now set, the current limited benefits make the work tedious without enough perceived benefit. This causes considerable variability in the quality of the current models. Any increases in complexity of the models, has the potential to make this even worse.

4 New Architecture

Our new system needs to enable a much more scalable system, extending it to more faculties, degree programmes and professions and a richer model, potentially linked to student transcripts and their evidence for individual learner models and data mining. We have designed a modular 4-tier design architecture:

1. RDBMS backend storing subject details (learning outcomes, assessments, teaching methods, competencies) and metadata (competency relations, subject-degree relations, versioning, etc.);
2. Service-oriented business-logic layer encapsulating and exposing all functionality as a set of discrete operations;
3. PHP/HTML/Ajax presentation layer for public and administrative interfaces for viewing, editing and reporting.

The complex mapping will use a Web 2.0 interface, shielding users from the underlying relational complexities and ensuring fluent, responsive interaction.

5 Conclusion and Future Work

Designing and maintaining tertiary education curricula challenging. It should support mobility of students between degree programmes, ensuring effective assessment of whether a student has met the institutional requirements, as well professional competency and accreditation requirements. Competency requirements drive design of University curricula, defining which subjects are part of each curriculum program. These subjects, with their learning outcomes, teaching methods and assessments, are the mechanism for ensuring that students will acquire competencies required.

[8] Competencies Working Group Recommendation, HR-XML Consortium, Inc., `http://ns.hr-xml.org/2_5/HR-XML-2_5/CPO/Competencies.html`

[9] IMS Reusable Definition of Competency or Educational Objective Specification, IMS Global Learning Consortium, Inc., `http://www.imsglobal.org/competencies/rdceov1p0/imsrdceo_infov1p0.html`

Previous work [6], [5], [2] indicates the need for curriculum designers to take care in addressing required competencies. What is not agreed, however, is the definition of competencies, the competencies that should apply internationally in a particular profession, or just how to ensure effective implementation. While some several learning standards are capable of modeling certain aspects of the problem, with EML appearing the most mature, the design of the learner models for our approach is challenging.

Our Engineering faculty has created a promising competency-to-subject mapping system and used it for three years. We now face the challenge of scaling this, generalising it for deployment across other faculties. We particularly want to model the support generic competency requirements, support linking competencies to subject learning outcomes, teaching methods and assessments, linking semantically related competencies across curricula and ensuring ease of use.

Some immediate benefits of such a system include easier tracing of the accreditation and professional competencies through a student's degree programme. This traceability will enable faculties to easily and quickly provide required evidence for accreditation reviews. The system will be of value for degree coordinators who need to evaluate and approve or reject a particular student's subject selections simply by comparing the student's current learner model against the degree learner models and to the competencies developed in the subject in question. Students will be able to see their developing learner model of competencies. This information aid their decisions on subject choices. It will be particularly valuable when a student changes direction to a new degree.

Further work includes exploring the generic or concept-specific word taxonomies to automate or supplement the competency relationship mapping process. For example, WordNet might help automatically map generic skills defined in different terms. We currently do not plan to make our new system compliant with learning standards we have described as none appears adequate. A combination of standards might help to model different data entities (for example, using IMS-RDCEO for competencies, EML for the subjects and LOM for the taxonomy paths or relation identifier. These might be tied in together using a relational model. Standards might improve interoperability with other systems, if any existed, at a cost of some additional complexity and little benefit for our core mapping problem.

The modular SOA implementation should support future educational data mining. For example, identifying subjects which contribute to overall success based on the competencies taught. Or exploring ways to restructure degree programmes to strengthen teaching of the core syllabus requirements. We also plan to track developments in LORNET TELOS ([7], [8]) developments with its power for semantic referencing of resources and competencies using taxonomies, ontologies and metadata tagging.

References

[1] The Bologna Declaration on the European space for higher education: an explanation, 1999.

[2] Tuning Educational Structures in Europe Final Report Pilot Project - Phase 1, 2005.

[3] Frans Van Assche. Linking Learning Resources to Curricula by using Competencies. 2007.

[4] Rob Koper. Modeling units of study from a pedagogical perspective: the pedagogical meta-model behind EML. In *OTEC*, 2001.

[5] M. Mulder, J. Gulikers, R. Wesselink, and H. Biemans. The new competence concept in higher education: error or enrichment? 2008.

[6] M. Mulder, T. Weigel, K. Collins, and B. Bibb. The concept of competence in the development of vocational education and training in selected EU member states–a critical analysis. *Analysis*, 59(1):65–85.

[7] Gilbert Paquette. An Ontology and a Software Framework for Competency Modeling and Management. *Educational Technology & Society*, pages 1–21, 2007.

[8] Gilbert Paquette, Ioan Rosca, Stefan Mihaila, and Anis Masmoudi. TELOS, a Service-Oriented Framework to Support Learning and Knowledge Management. *E-Learning Networked Environments and Architectures: A Knowledge Processing Perspective*, page 434, 2007.

[9] Valéry Psyché, Jacqueline Bourdeau, and Riichiro Mizoguchi. Ontology Development at the Conceptual Level for Theory-Aware ITS Authoring Systems. In *AIED*, pages 491–493, 2003.

A APPENDIX - Competency Definition Examples

A.1 University of Sydney Generic Graduate Attributes

The University of Sydney defines a generic set of skills[10] that are common to all graduates upon completion of any offered degree programme. The following is a definition of a single skill category, namely *Research and Inquiry*:

1. Be able to identify, define and analyse problems and identify or create processes to solve them;
2. Be able to exercise critical judgment and critical thinking in creating new understanding;
3. Be creative and imaginative thinkers;
4. Have an informed respect for the principles, methods, standards, values and boundaries of their discipline and the capacity to question these;
5. Be able to critically evaluate existing understandings and recognise the limitations of their own knowledge.

A.2 Faculty of Engineering Graduate Attributes

Each Faculty or School typically develops their own set of domain specific generic skills that inherit from the broadly University set. The following is an extract of the *Research and Enquiry* definitions from the Faculty of Engineering Graduate Attribute Policy Statement:[11]

1. An appreciation that engineering fundamentals are based upon the principles and knowledge of science and mathematics;
2. An ability to apply engineering fundamentals along with the basics of science and mathematics to engineering problem solving;
3. The recognition of the rapid and sometimes major changes in technology and to value the importance of continual growth in knowledge and skills;
4. An ability to exercise critical decision making in defining solutions, and an understanding of the design process within engineering;
5. An understanding of engineering processes and principles which assist in the design and manufacture of products and systems;
6. An ability to design and conduct experiments and to analyse and interpret data from those experiments;
7. An appreciation that systems are composed of components spanning the whole of the engineering discipline, and that a basic understanding of the concepts behind these disciplines outside of ones own is important.

Mapping these domain-specific Engineering attributes to the University generic attributes could be loosely done as follows ([engineering attribute -> [university attribute,...]]): [1->4],[2->1],[3->2,5],[4->1,2,5],[5->4],[6->1,2],[7->3,4,5].

A.3 Faculty of Science Graduate Attributes

Likewise, the Faculty of Science defines its own interpretation of the University Research and Enquiry generic attributes as follows:[12]

1. An ability to engage in an examination of truth and validity in scientific argument and discourse and evaluate the relative importance of ideas;
2. An ability to apply scientific knowledge and critical thinking to identify, define and analyse problems, create solutions, evaluate opinions, innovate and improve current practices;
3. An ability to gather, evaluate and deploy information relevant to a scientific problem;
4. An ability to disseminate new knowledge and engage in debate around scientific issues;
5. The recognition of the rapid and sometimes major changes in scientific knowledge and technology, and to value the importance of continual growth in knowledge and skills;
6. An ability to design and conduct experiments and to analyse and interpret data from those experiments;

A similar mapping process is used to reflect the relationships between each of these definitions to the University level definitions.

[10] Generic Attributes of Graduates, University of Sydney, `http://www.itl.usyd.edu.au/graduateAttributes/policy_framework.pdf`

[11] Faculty of Engineering: Contextualised Graduate Attributes, University of Sydney, `http://www.itl.usyd.edu.au/graduateAttributes/facultyGA.cfm?faculty=Engineering`

[12] Faculty of Science: Contextualised Graduate Attributes, University of Sydney, `http://www.itl.usyd.edu.au/graduateAttributes/facultyGA.cfm?faculty=Science`

A.4 EA Stage 1 Competency Assessments

All degree programmes pertaining to the Faculty of Engineering must also support a list of formal accreditation competency requirements as stipulated by the Engineering Australia Stage 1 Competency Assessments documents.[13] Examples of these include:

1. Recognise limits to own knowledge and seek advice, or undertake research, to supplement knowledge and experience;
2. Take charge of own learning and development. Understand the need continually to review own strengths, determine areas for development and undertake appropriate learning programs;
3. Commit to the importance of being part of a professional community: learning from its knowledge and standards, and contributing to their maintenance and advancement;
4. Improve non-engineering knowledge and skills to assist in achieving engineering outcomes;
5. Demonstrate appreciation of the evolving nature of engineering and technology, and readiness to tackle new issues in a responsible way;
6. Demonstrate a sense of the dimensions and level of challenge of projects and programs, and related information requirements, based on reasoning from first principles and on developing experience.

These competencies can be mapped to the Engineering Specific Graduate Attributes defined earlier, and thus also to the University Generic Attributes.

A.5 Association for Computing Machinery Curricula Requirements

Similarly, whilst School of Information Technology degree programmes do not have formal accreditation competency requirements, they must still support the Faculty of Science Generic Attributes and also external curriculum recommendations specified by the Association for Computing Machinery (ACM).[14] A few examples of the ACM requirements are:

1. Demonstrate knowledge and understanding of essential facts, concepts, principles, and theories relating to computer science and software applications;
2. Use such knowledge and understanding in the modeling and design of computer-based systems in a way that demonstrates comprehension of the tradeoff involved in design choices;
3. Identify and analyze criteria and specifications appropriate to specific problems, and plan strategies for their solution;
4. Understanding the elements of computational thinking. This includes recognizing its broad relevance in everyday life as well as its applicability within other domains, and being able to apply it in appropriate circumstances.

The ACM also lists several sets of topic-based learning outcomes and low-level fine-grained competencies such as:

1. Explain the use of big O, omega, and theta notation to describe the amount of work done by an algorithm;
2. Use big O, omega, and theta notation to give asymptotic upper, lower, and tight bounds on time and space complexity of algorithms;
3. Determine the time and space complexity of simple algorithms;
4. Deduce recurrence relations that describe the time complexity of recursively defined algorithms.
5. Solve elementary recurrence relations;

School of Information Technology degree programmes should also pay close attention to ACS (Australian Computer Society)[15] policies and recommendations, and Faculty of Engineering degrees in the IT/Computer Science profession should adhere to the ACM and ACS recommendations as well as the EA Stage 1 accreditation requirements.

[13] Stage 1 Competency Assessments, Engineering Australia, `http://www.engineersaustralia.org.au/about-us/join-engineers-australia/stage-1-competency-assessments.cfm`

[14] Curricula Requirements, Association for Computing Machinery, `http://www.acm.org/education/curricula-recommendations`

[15] Australian Computer Society, `http://www.acs.org.au/`