
A Unified Model for Embedding Learning Standards into University Curricula for Effective Accreditation and Quality Assurance

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BACKGROUND

Accreditation review boards, degree program coordinators, employers and other stakeholders need to be able to answer the question: what do students learn in a degree program, and how well do they learn it? Our aim is to empower these stakeholders with a systematic approach for answering this, and other important questions about the curriculum. The paper describes the use of learner models that represent the intended vs. actual knowledge of each graduate in terms of learning goals of the institution and of relevant external accreditation and professional bodies. The conceptual model presented achieves this for both broad generic graduate attributes and for fine grained learning goals using curriculum mapping and learner modelling theory.

PURPOSE

The key research questions for this study are:

1. How do we effectively integrate the multiple sets of internal and external graduate learning goals (accreditation competencies, graduate attributes, AHELO, TEQSA, etc.) into a degree program?
2. How do we effectively integrate fine-grained syllabus specifications, which generally define large numbers of very specific topics and outcomes, into full three-to-five year degree programs?
3. How do we effectively define the learning of progressive mastery levels in comparable and unambiguous terms?

DESIGN/METHOD

To tackle these problems, we designed a unified conceptual model that supports mapping of various graduate attributes, accreditation competencies, learning outcomes and curriculum guidelines against the learning activities, assessments and subjects across entire university degree programs. We systematically implemented and evaluated key components of this model to validate the feasibility and effectiveness of the conceptual design.

RESULTS

A light-weight semantic mapping approach for capturing the relationships between different graduate learning goal frameworks was deployed in a live university environment and used to map over 300 degree programs from three diverse faculties to over 30 different learning goal frameworks. The faculties involved have adopted the system into their program quality control and review workflows, which has led to identification of unit sequencing issues and gaps in attributes/competencies taught. A second curriculum modelling system was used to train and support academics in using formal cognitive development theories to effectively specify mastery levels and ensure progression in curriculum design against detailed syllabus specifications. The approach was evaluated and demonstrated to be feasible and highly valuable for determining program compliance with authoritative curricula.

CONCLUSIONS

The systematic approaches to curriculum design described in this paper have shown great promise as effective means to deal with the increasing focus on standard learning goals, increasing accreditation requirements, and increasing need for having comparable curricula across different institutions. The conceptual model described has been implemented and evaluated with real degree programs across multiple institutions and multiple disciplines. The design and findings can serve as a foundation for other institutions developing similar systems in response to new quality assurance requirements.

KEYWORDS

Curriculum design, accreditation, learning standards, syllabus specification, progression

Introduction

Due to the continuing globalization of the workforce, there is an increasing international need for standardization, accreditation and certification of university engineering degree programs (Prados et al. 2005, Patil & Codner 2007, Yeargan & Hernaut 2001, Swearingen et al. 2002, Vest 2008). This standardization is important in ensuring that an employer seeking to hire an engineering graduate can compare candidates from different institutions. To this end, many government bodies, professional organizations and institutions have created standard curricula guidelines, syllabus outcomes, learning goals, accreditation competencies and graduate attribute statements that learners are expected to have at the completion of a degree program (as exemplified in the Background section below). Systematically integrating these diverse standards into degree programs is a non-trivial task that requires new approaches to curriculum design.

Various stakeholders need to be able to answer a number of questions. For example, degree coordinators must answer: What are the learning goals that need to be taught and assessed in degree X? Does the degree teach and assess all of these goals at a level satisfactory for compliance reviews? How can we show an accreditation panel that degree X satisfies these learning goals? Subject lecturers and coordinators may have additional questions, such as: How does my subject fit into the degree(s) in which it is offered? What are the relevant learning goals that my subject needs to teach and assess? What skills and knowledge can I expect of students enrolling in my subject? What generic graduate attributes must I assess for, and to what standard? Answering these all questions is non-trivial, as a three-to-five year degree may have 24 to 40 core and elective subjects.

This paper presents a unified information system for curriculum design. The system uses long term institutional learner models that represent the intended curriculum throughout the degree. It provides solutions to the following three key challenges:

1. A single degree program may need to be accredited or reviewed against multiple sets of internal and external learning goal standards. How can this be done effectively without excessive administrative overheads?
2. Fine-grained syllabus specifications can define large numbers of expected topics and outcomes. How can institutions effectively integrate and report against such detailed specifications?
3. Learning is progressive and students acquire knowledge at different levels of mastery. How do we unambiguously define mastery levels to ensure progression in the curriculum, to differentiate between bare-passing students vs. top-performing students, and to compare students from different institutions on equal grounds?

We have previously published about sub-components of the above problems in isolation:

1. Gluga, Lever & Kay (2012) described a light-weight semantic modeling approach for pragmatically dealing with the complexity of multiple generic learning goals from multiple sources.
2. Gluga, Kay, Lister, Kleitman & Lever (2012) detailed an interactive web-based tutorial system for training academics on how to consistently apply a classification scheme such as Bloom's Taxonomy, for coding the difficulty of exam questions and other assessment tasks.
3. Gluga, Kay & Lister (2012) presented an approach for modeling the assessments across the subjects of a degree against the very fine-grained ACM/IEEE 2013 Computer Science curriculum guidelines, at specific levels of mastery.

This paper for the first time brings together all of these individual elements into a unified conceptual model that may be used as a foundation for future university curriculum design and accreditation practices. We present the details of this conceptual model, describing how each of the previously published components integrates into the model.

Background

The need for better support for integrating learning goals into university degrees is recognized by many, including Mulder et al. (2007) who discussed the growing need for standards-based design of university curricula in Europe. They reported on various European projects, noting the need for better quality control and integration of learning goal standards, but the lack of supporting technology. McKenney et al. (2002), also identified the need for more effective tools and techniques to support curriculum designers.

Complexity of Learning Standards

Consider, for example, a Bachelor of Engineering in Software Engineering degree offered at an Australian university. The curriculum of this four year degree must align with a number of different institutional, national and professional learning goals such as:

- University Graduate Attributes (Graduate Attributes policy 2011),
- Contextualized Faculty of Engineering Graduate Attributes (Engineering and IT Graduate Outcomes Table 2012),
- Engineering Australia Stage 1 Competency Standards (Stage 1 Competency Standard for Professional Engineer 2011)
- ALTC LTAS Threshold Learning Outcomes for Engineering and ICT (Engineering and ICT Learning and Teaching Academic Standards Statement 2010)

The numerous learning activities and assessment tasks that make up each of the 30+ core and elective subjects of this degree must define a learning path over the four years of study. That is, a faculty graduate attribute or accreditation competency may be introduced and assessed at a novice level in a first semester subject, and developed and assessed at a more advanced level in successive subjects of study.

A university may also aspire to accredit against important international learning standards, in which case this Software Engineering degree may need to align with some or all of the following (in addition to the learning goals from above):

- Tuning-AHELO Expected/Desired Learning Outcomes in Engineering (A Tuning-AHELO Conceptual Framework of Expected/Desired Learning Outcomes in Engineering 2009)
- Worldwide CDIO Initiative, Standard 2 - Syllabus Outcomes (12 CDIO Standards 2012)
- Accreditation Board for Engineering and Technology - Software Engineering (ABET-SE) (Criteria for Accrediting Engineering Programs 2011)
- ACM/IEEE Software Engineering Curriculum Guidelines 2004 (Software Engineering 2004 Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering 2004)

These different learning standards vary in level of granularity and specificity. The difficulty of ensuring appropriate level of granularity is a recurrent and so far unresolved issue in learning standards formulation from 1990s competency standards development (Gonczi et al. 1990) through to present day graduate outcome initiatives (Yorke 2011). For example, generic University Graduate Attributes describe high-level transferable skills. Engineering Australia accreditation competencies, AHELO Learning Outcomes and ABET-SE accreditation standards are more fine-grained and contextualized to the engineering profession. Going further still, the ACM/IEEE Software Engineering Curriculum Guidelines (SE2004) presents a detailed Body of Knowledge that specifies 320+ topics and learning objectives which Software Engineering degrees are expected to cover in the curriculum.

Curriculum Mapping

The concept of curriculum mapping was introduced by Hausman (1974), and later refined by English (1978, 1980 and 1988). English defined curriculum guidelines, behavioural objectives and course outlines as “descriptions of a future desired curriculum”, which he simply labelled as the “fictional curriculum” (English 1978). He stated that “to exercise quality

control over curriculum requires the instructional leader or supervisor to know what the *real* curriculum is in his or her subject area" and unless the real curriculum is "known and quantified, it is not possible to understand ... existing gaps or holes".

These ideas led Jacobs to develop a number of systems for K-12 education in the United States (Jacobs 1989, 1991, 1997 and 2010). In universities, curriculum mapping has been adopted primarily in the medical domain (Davis & Harden 2003, Harden 2001, Harden et al. 1997, Prideaux 2003).

Evidence of such systems in university engineering education is sparse however. A limited implementation of attribute-to-subject mapping was employed by Calvo et al. (2007) in their Curriculum Central (CC) system. It had a single attribute framework against which subject learning activities and assessments could be mapped. However, CC could not deal with multiple learning goal frameworks, or with the complexity of elective subject choices. Bull & Gardner (2009) mapped multiple choice questions from several subjects to UK SPEC Standards for Professional Engineering attributes using their UK-SPECIAL system, which did not support complex degree program structures or multiple learning goal frameworks either.

Long Term Learner Modelling

One way to view the curriculum design challenge is to treat it as a form of Learner Modelling, which emerged from research on Intelligent Tutoring Systems (ITS). Learner models describe what a learner knows at a particular point in time (Self 1994, Self 1999, Self et al. 2002). The literature on learner modelling defines some key concepts that can also be used to model accreditation competencies, graduate attributes and learning outcomes:

- *Overlay Model* – represents the knowledge and concepts of an expert in the field (Carr & Goldstein 1977). That is, an overlay model is the desired end-goal of a learner model. Overlay Models are also sometimes referred to as Domain Models or Expert Models.
- *Stereotype Model* – represents the knowledge and concepts a learner would be expected to acquire after completing a set of learning activities (Rich 1979). That is, a stereotype model is a prediction of a learner model (Kay 2000).
- *Open Learner Model* – a model where the learner (or teacher) can inspect a visual representation of the learner model (Bull & Gardner 2009). This concept can be applied to either of the above model types.

In our work, we apply these learner modelling concepts at a much higher level. That is, instead of modelling the concept ontology of a single subject, we model higher-level learning standards that encompass the knowledge and concepts acquired at the end of an entire university degree. This is a departure from learner models as used in ITS systems. However, the underlying principles apply equally well at this higher level, and provide us with a language and mechanism for defining our unified model for curriculum design that we are about to describe.

Unified Model for Curriculum Design

We now present a conceptual design for a unified long-term institutional learner modelling approach. The aims of this model are to solve the following key problems:

- **Problem 1:** How to effectively integrate multiple sets of internal and external graduate learning goals (accreditation competencies, graduate attributes, AHELO, TEQSA, etc.) into a single degree program?
- **Problem 2:** How to effectively integrate fine-grained syllabus specifications, which generally define large numbers of very specific topics and outcomes, into full three-to-five year degree programs?
- **Problem 3:** How to effectively define the learning of progressive mastery levels in comparable and unambiguous terms that can be agreed upon by multiple stakeholders and educators?

Overlay Models, Program Goals and the Refined Model

Figure 1 shows the main components of this conceptual model. We begin by treating the different learning goal sets that a degree program may aspire to align with as the *Overlay Models*. That is, each learning goal set is captured as an independent *Overlay Model*. These *Overlay Models* represent the target *Learner Models* that we expect of graduating students. Note that the *Overlay Models* are of different granularity, as described earlier. The coarse high-level learning goals from these *Overlay Models* are mapped to a *Program Goal Matrix* (PGM), which we refer to as a *Refined Model*. This PGM is constructed as a two-dimensional matrix that defines a set of Program Goals, and for each goal, defines a set of contextualized level descriptors. For example, a Program Goal for a degree may be “*Design and Problem Solving Skills - Ability to work both creatively and systematically in developing effective, sustainable solutions to complex practical problems*” and a Level 1 (novice) descriptor may be “*Ability to analyse standard technical problems and evaluate potential causes and solutions*” (Engineering and IT Graduate Outcomes Table 2012).

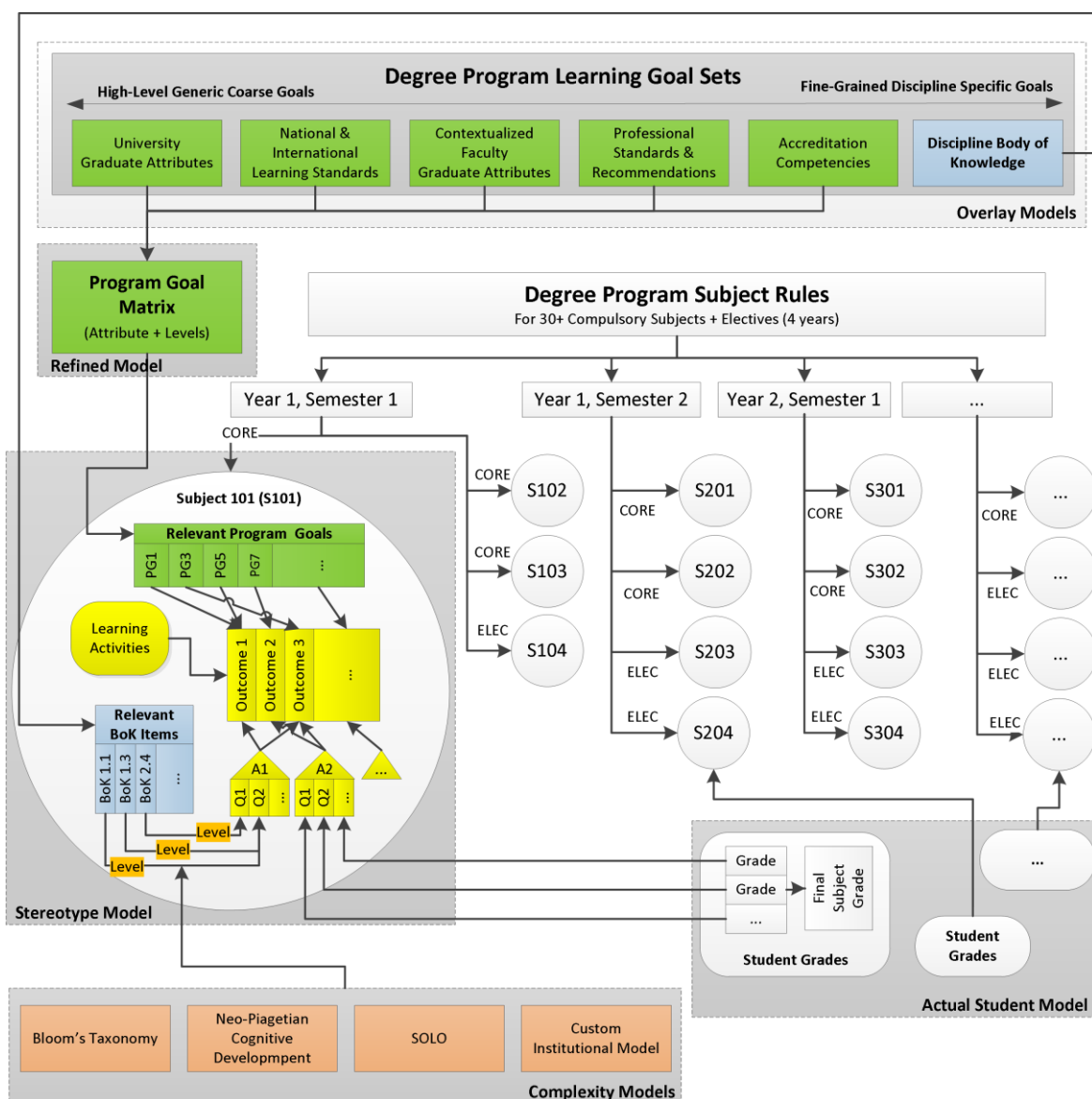


Figure 1 - Conceptual design for long-term institutional learner modelling

Each contextualized *goal-level* descriptor from the PGM is then mapped to relevant learning goals from the coarse *Overlay Models*, thus capturing the intention of multiple *Overlay Models* into a single *Refined Model*. This process works in general because of the semantic

similarities between these coarse learning standards (Gluga & Kay 2009). However, fine-grained discipline specific skills, such as the ACM/IEEE SE2004 Curriculum Body of Knowledge topics and outcomes, are not mapped to this high-level *Refined Model*, as the granularity difference is too great (the SE2004 BoK specifies 320+ topics and outcomes (Software Engineering, 2004), which may map to just one or two assessments or lectures in one subject).

Subjects and Program Subject Rules

The *Degree Program Subject Rules* box at the upper right of Figure 1 represents the typical structure of an Engineering degree in Australia. That is, such a degree is typically four years long, with two semesters per year, and four subjects per semester. This usually includes a combination of compulsory and elective subjects.

Towards the bottom-left of Figure 1 we show an expanded subject, labelled S101. This subject is represented as follows:

1. A collection of *Relevant Program Goals* from the *Program Goal Matrix*, as defined by the degree program curriculum designer. These *Relevant Program Goals* represent the prescribed component of what the subject is expected to teach and assess, to ensure alignment with other subjects in the program sequence.
2. A collection of *Learning Outcomes*, as defined by the subject lecturer. These *Learning Outcomes* are required to align with the prescribed *Relevant Program Goals*. Additional outcomes may be added by the lecturer that covers non-prescribed content.
3. A collection of learning activities (lectures, labs, practical exercises, etc.) which align with the Learning Outcomes defined above.
4. A collection of *Assessment Tasks* (represented as A1, A2, etc.) that measure student performance on the Learning Outcomes.

In addition to the high-level *Prescribed Program Goals* from the *Refined Model*, a subject lecturer may also wish to align learning activities and assessments with *Relevant Body of Knowledge* or other fine-grained learning goals that are not captured in the *Refined Model* (such as the SE2004 BoK). These fine-grained goals may be mapped directly to the assessment tasks and sub-tasks, at specific mastery levels.

Each core and elective subject in the degree program sequence may be modelled in this fashion. The mappings of *Learning Outcomes* and *Assessment Tasks* from each subject to the relevant program goals and syllabus outcomes may then be treated as *Stereotype Models* (i.e. the predicted learning of students who successfully complete each subject). The *Stereotype Models* are open to inspection by academic staff via visualizations and charts that show expected learning across a full degree program. These models are thus able to represent the intended learning in the curriculum against the *Refined Model*, the high-level *Overlay Models* and also the fine-grained discipline-specific *Overlay Models*.

Capturing Progression via Complexity Models

Each *Relevant Body of Knowledge* item is mapped to assessment tasks at appropriate levels of mastery. This is necessary to capture progression over the subjects of the curriculum. These levels of mastery need to be agreed upon by the different curriculum design stakeholders (subject lecturers, program designers, accrediting panel). As such, the mastery levels are encapsulated as *Complexity Models* (CM). These are systematic representations of difficulty/mastery that a group of stakeholders may use consistently within the context of a degree program or discipline, such as Bloom's Taxonomy (Bloom et al. 1956), SOLO (Biggs & Collis 1982) or others.

Stereotype Models vs. Actual Student Models

Stereotype Models may either represent the *aspirational standards* (i.e. a learner who performs well in all assessments and thus learns all mapped learning goals to the intended standard), or the *minimal pass standards*. These two alternatives are useful for inspecting

the learning design of the curriculum as a whole, to ensure a program complies with minimal accreditation standards, and to show how a program goes beyond these minimal standards.

Actual Student Models or *Learner Models* may be generated by integrating the subject design with a grading system that captures detailed student marks for each assessment task. Such a *learner model* could be used during accreditation as exemplars of actual student achievement, especially if linked to a portfolio system holding actual student graded work.

Evaluation

We have implemented the described conceptual design as a number of components, and evaluated the effectiveness of each to answer the three key questions identified earlier. The implementation and evaluation details of these components have been published separately. We thus provide here only a summary of these evaluations.

Problem 1: Effectively integrating multiple high-level learning standards into whole-of-program curricula

The effectiveness of our solution to this problem has been demonstrated through the CUSP system (Course & Unit of Study Portal, Gluga, Lever & Kay 2012). CUSP is in live production use at the University of Sydney. It presently models 300+ degree program structures and over 5000 subject sessions for the 2012 academic year. The learning outcomes from each subject are mapped to relevant PGM models for each program, which are in-turn mapped to over 30 different internal and external *Overlay Models*, across three faculties (Engineering, Architecture, Health Sciences).

A key concern of this *Refined Model* approach is the ability to maintain accuracy in the cross-mappings between the different learning goal sets. That is, subject *Learning Outcomes* are mapped to goals in the *Refined Model*, which are mapped to goals in the *Overlay Models*. So how accurately do subject *Learning Outcomes* map to the *Overlay Models* via this indirect approach? This was evaluated in Gluga, Lever & Kay (2012), where results showed that while the approach is not error-free, the accuracy rate is high enough as to be useful. In cases where translation errors are found, these may be corrected by either tuning the subject learning outcomes or the *Refined Model* mappings.

Since the system was deployed in 2010, the Open Stereotype Models have been used by program coordinators to describe and refine the curriculum design of the modelled programs. The visualizations and reporting tools in the system allow for quick identification of learning goal gaps or sequencing errors. Over time, these reports have led to refinements to subject outlines, assessment tasks, and program structures.

Problem 2: Effectively integrating fine-grained syllabus specifications into whole-of-program curricula

The effectiveness of our solution to this problem was demonstrated by a separate system implementation named ProGoSs, described in Gluga, Kay & Lister (2012), where we mapped the core subjects from a Computer Science program to the Relevant Body of Knowledge topics and outcomes specified in the ACM/IEEE CS2013 Curriculum Guidelines, which lists 1366 topics and 1041 learning objectives. Results indicated that the approach and system implementation were feasible in two respects. First, the interfaces allowed for rapid data-entry, only taking up to two hours for mapping a subject to this fine-grained specification. Second, the open *Stereotype Model* visualizations provided a rich and easy to interpret representation of the program compliance with the standard. The academics who participated in the evaluation indicated that they would use such a system if they had to show compliance to a syllabus specification.

Problem 3: Effectively defining learning progression and mastery levels

Defining effective learning progression across a degree requires stakeholders to have a shared language for describing mastery levels. Many cognitive development theories may be

used for this purpose, such as Bloom's Taxonomy (Bloom et al. 1956), SOLO (Biggs & Collis 1982) and Neo-Piagetian Cognitive development theory (Lister 2011). As described in Gluga, Kay, Lister, Kleitman & Lever (2012) however, previous attempts to apply these theories have not been overly successful due to lack of inter-rater agreement. We thus developed a system for defining a generic *Complexity Model*, contextualized it to a discipline, and trained stakeholders on how to apply that *Complexity Model*. Specifically, we evaluated the effectiveness of our system with Bloom's Taxonomy (Gluga, Kay, Lister, Kleitman & Lever 2012) and with Neo-Piagetian theory (Gluga, Kay, Lister & Teague 2012) in classifying computer science programming exam questions. Results indicated the training system is effective at increasing stakeholder confidence in using such classification schemes.

Conclusions

We have presented a unified model for curriculum design, based on curriculum mapping and learner modeling theory that effectively mitigates the complexity of complying with multiple accreditation standards. The various components of this model have been implemented and evaluated individually in earlier publications. This paper for the first time brings together those components into a unified conceptual model.

The modularity of the system means that an institution may choose to focus on only high-level coarse goals, and thus only implement the *Refined Model* Program Goal Matrix approach. Or an institution may choose to focus on compliance with highly-prescriptive Body of Knowledge for a specific degree program or discipline. Likewise the *Complexity Model* component is not essential if progression across learning goals is not a desired program design requirement.

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