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A curriculum design, modelling and visualization environment

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BACKGROUND

The development and deployment of curricula is at the heart of engineering education. Curriculum design is a complex activity with many integrated knowledge domains and tasks. The design of curricula share many common elements with engineering design.

It is important to develop cohesion in the curriculum ensuring all elements work in harmony to deliver stated outcomes. There is a need to have robust computer aided tools to help academe in designing curricula, understanding key characteristics of those curricula, as well as allowing students to gain deeper insight into their individual learning pathways.

PURPOSE

This work creates a prototype software environment for curriculum design that permits users to integrate knowledge, attainment levels, learning outcomes and assessment tasks so as to build learning pathways, then view and assess their characteristics.

DESIGN/METHOD

The design elements are based on defining formal data structures such as ontologies and taxonomies for such areas as discipline knowledge domains, sub-domains and topics; assessment types; learning places and spaces; the creation of structured learning outcomes and other curriculum elements. These are made available to the user in a fully configurable and customizable interface with a back-end database. The prototype allows courses and whole curricula to be constructed and then examined for a range of characteristics. Understanding a range of characteristics of the curriculum is facilitated through a user questioning facility and various display modes. The development has received input from psychology and the reference group now includes science.

RESULTS

The current development has defined and implemented much of the underlying data structures that allow curricula to be constructed. Structured generation of specific learning outcomes for both cognitive and affective domains can be done. The development of linking capabilities addressing required prior learning (RPL) and to future anticipated learning (FAL) allows pathways to be traced across and within semesters. Incremental development of knowledge areas and professional skills/attitudes can be designed and tracked. A number of curriculum design case studies in chemical engineering have been used to test functionality.

CONCLUSIONS

The environment will allow academics to systematically build and assess curricula. It allows academics to have deeper insights overall curriculum and assessment architectures. Students will better understand the learning and assessment pathways within their degree programs. Enhancements to the prototype will help deliver the full benefits to the user.

KEYWORDS

Curriculum design, assessment ontologies, knowledge taxonomies, learning outcomes, graduate outcomes, learning pathways, academic standards.

Introduction

The creation of curricula is a key activity in education and one that has a long history (Dewey 1916, Tyler 1949). At its heart is the design of learning pathways for students towards end-goals. End-goals are often expressed in a range of terms such as graduate capabilities, competencies or attributes. These learning outcomes are developed incrementally during the learning journey thus leading to final graduate outcomes.

The word 'curriculum' has an informative and important etymology, which helps focus the curriculum designer on the key design intentions. In Latin, *currere* is the verb 'to run', and a 'curriculum' related to a Roman race track or pathway. Designing learning pathways can be a complex task and bears many similarities to engineering design of processes that deliver specific outcomes from a set of inputs.

Recent interest in curricula is highlighted by Barnett & Coate (2005) in their important work in 'engaging the curriculum' in higher education. It emphasized the need to understand curricula in terms of student engagement through Knowing, Acting and Being. Here, the concepts of KAB forms a schema which:

"recognizes that curricula have distinctive but integrative components, as well as allowing for different weightings of each domain within any one curriculum". (p70).

In his work on Australian curriculum issues, Hicks (2007) emphasised the lack of real interest in curriculum in Australian higher education, noting that:

"'Curriculum' is a term that has been given little currency, or at least little profile, in higher education in Australia. Either a limited 'content' focused use of the term is assumed, or the term is used as a vehicle for the discussion of critical issues in higher education e.g. 'inclusive curriculum', 'learner-centred curriculum', 'internationalising the curriculum'".

Kift & Nelson (2005) recognised the importance of curriculum design in the context of aiding students in their transition to higher education. They saw the need *"to establish coordinated, curriculum-mediated transition practices … so that students successfully engage with their learning experience."* The importance of coherent cumulative units was seen an essential part of the curriculum design process.

Other, key drivers in engineering curriculum design come from professional bodies such as Engineers Australia (EA), and most recently from the newly established Tertiary Education Quality & Standards Agency (TEQSA). In the case of EA, the professional accreditation standards and competencies, expressed in the Stage 1 Competency Standards centre around similar schema particularly around addressing learning outcomes and the processes required to achieve those outcomes (EA 2012, TEQSA 2012).

TEQSA in a regulatory role will bring teaching and learning standards and quality assurance (QA) processes to bear on programs in higher education. This involves the use of risk and proportionality principles, teaching and learning standards together with the overarching role of the Australian Qualification Framework (AQF). It is essential for HE institutions to show how degree programs, and *inter alia* curricula help deliver the requisite AQF level characteristics for a specific qualification. It is also clear that TEQSA under its regulatory role will not delegate its responsibilities to professional bodies. These external influences will have important flow-on effects for curriculum design.

Besides the external drivers around curriculum design, there are the numerous internal institutional reasons to fully understand the nature of the learning pathways, the development of learning outcomes, knowledge areas and the application and personal skills to address increasingly complex issues. Coupled with this are the imaginative ways, spaces and places where students can be challenged and encouraged in their learning as well as assessed for learning and performance.

As the curriculum is a shared responsibility of a school or department, it is vital that individual academic responsibilities for learning units be understood very clearly in the context of the whole curriculum. As well, students should be able to see the intended learning pathways to graduation, appreciate their connections and the learning processes that will lead them to the goal.

In recent years it has been evident that institutions and individuals have developed a range of mapping tools in an attempt to see where certain learning outcomes appear in current curricula and how they might address institutional graduate attributes or professional competencies or capabilities. These include *CCMap* (Oliver et al. 2010) and *CCMapper* (Roy & Armarego 2012), plus many others internal to institutions. The *CCMap* tool is an Excel workbook with facilities that provide learning outcome descriptions, levels of thinking, graduate attributes development and forms of visualization. The CCmapper tool is similar but focussed on the engineering discipline.

The intent of the authors’ work is far more wide-ranging. We wish to create not just a mapping tool, but a comprehensive design tool that provides the ability to rate existing curricula but also generate multiple curriculum alternatives that are functionally similar. In seeking to achieve this we are partnering with other disciplines such as psychology and science to ensure the functionality is sufficient to allow any discipline to gain benefit from the current developments.

The following sections discuss the necessary functionality of a curriculum design environment and the requisite components within the design environment that permit the curriculum to be established and interrogated. We show the formal structures components and how these have been implemented within a prototype environment. We give some illustrations of the early application of the environment to a curriculum case study, finishing with some ideas for future work.

Curriculum design and environment functionality

Design of engineering curricula is not just a simple task of filling up a chronological chequer board with individual learning modules, or a singular focus on knowledge acquisition or even ticking a set of boxes around learning outcomes. It is about a design process that leads to a cohesive, progressive and imaginative creation of pathways for student learning. Similar to engineering design, curriculum design has a significant array of components that in concert deliver the intended learning outcomes and experiences for students.

The authors are aware that there can be significant differences between the ‘intended’ curriculum and the ‘delivered’ and ‘experienced’ or ‘lived’ curriculum.

Much has been written and investigated in this area, including the UK JISC activities on The Design Studio, which brings together a range of resources for curriculum design and delivery (JISC 2012).

The following section sets out the functionality of the environment.

Environment functionality

The intended functionality of this environment includes:

1. The ability to describe knowledge and skill domains and their interlinking through semesters and across years,
2. The ability to describe and track intended learning outcomes (LOs) and attainment levels across space and time,
3. The ability to describe the context and complexity of the planned learning,
4. The ability to describe the spaces and places where learning is planned to happen,

5. Ability to link assessment activities to LOs and learning activities for promoting learning and proving outcomes,
6. Ease of use by program coordinators and academic staff,
7. Use by students to gain insight into the characteristics of a designed curriculum, and potentially to design and track the ‘experienced’ curriculum,
8. The ability to interface to other systems such as institutional course/subject profiles,
9. The ability to embed within the environment current ‘best practice’ concepts and design processes as a vehicle for innovative curricula and better informed academic use,
10. The ability to adapt the environment across disciplines.

All these elements must ultimately consider many varied characteristics of the learner. The importance of student characteristics within curriculum design has been emphasized both nationally and globally for decades.

Defining, organizing and using curriculum components

The basic components

In addressing curriculum design environments there are several system components required in order to deliver the required functionality of the environment. These include two types of knowledge:

1. Generic knowledge
2. Specific knowledge

Generic knowledge refers to static but extensible or editable concepts, which are not dependent on the specific application or situation being considered. These could include outcome or competency standards such as those published by Engineers Australia (EA, 2012). In contrast, *Specific knowledge* depends on the individual application or context being considered. This might be related to a specific subject or degree program and the associated learning outcomes. The environment allows curriculum design to meet any stated outcomes, not just EA requirements.

A further issue is that *Generic knowledge* must be easily editable and extensible, requiring flexible data structures to be adopted within the environment.

The work here creates a number of important generic structures that facilitate the development of curricula and importantly interrogation of the structure and characteristics of curricula to generate deep insights into the design. An important aspect of the current work is to create an environment that is completely adaptable and extensible across disciplines. Amongst the *Generic knowledge* are the following components:

1. Description of knowledge domains, sub-domains and topics $\{KD_i, SD_j, T_k\}$, $i=1(1)n_1$, $j=1(1)m_1$, $k=1(1)p_1$.

   For example: $\{KD_1\ SD_1\ T_1\} \equiv$ {Mathematics, Linear systems, matrix inversion}, where there are many more topics T_k besides ‘matrix inversion’. This forms a knowledge taxonomy as seen in Figure 1. Taxonomies can also be created to describe skills, attitudes or other domains of interest.

2. Description of the attainment levels $\{A_i\}$, $i=1(1)p_2$.

   For example, these can be drawn from Bloom, Krathwohl, CDIO (Conceive, Design, Implement, Operate) and the like (Bloom et al. 1956, Krathwohl 2002, Crawley et al. 2007).

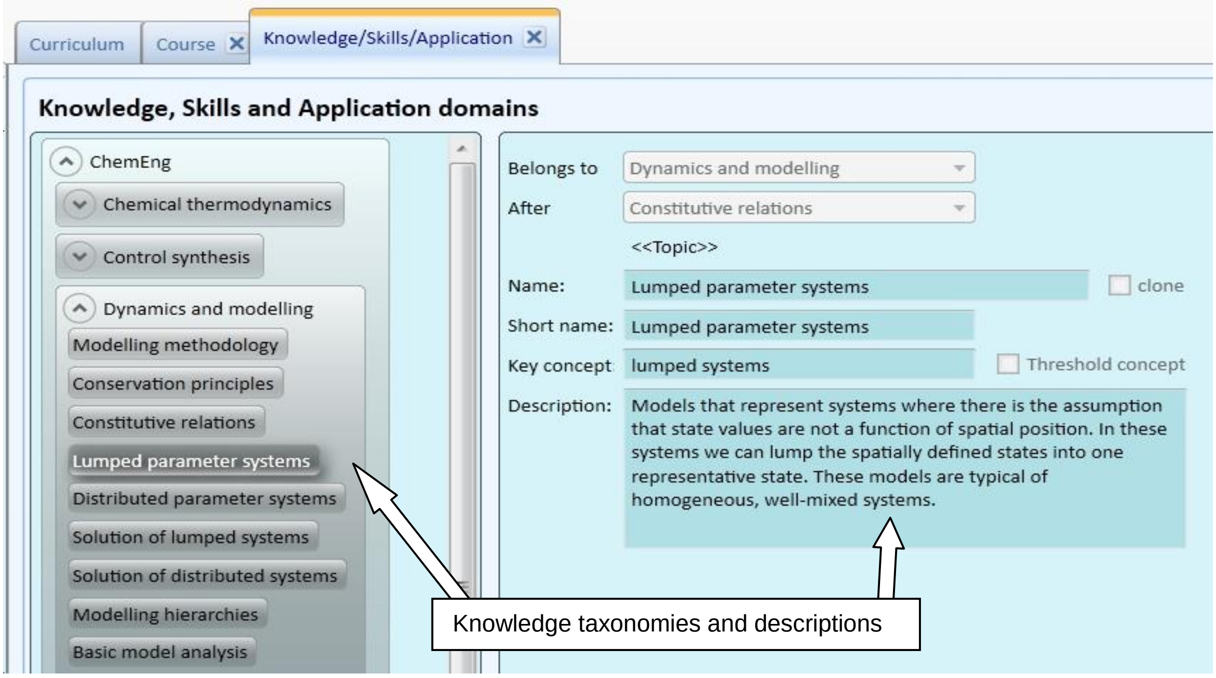
3. Description of the contexts $\{CO_i\}$, $i=1(1)p_3$ in which the learning occurs. This could be: *urban civil design*, *general process systems, environmental systems,* etc.
4. Levels of learning or application complexity within the context $\{C_i\}$, $i=1(1)p_4$

   For example, {'well-defined', 'broadly defined', 'complex', …, 'super-complex'}.
5. Description of the learning spaces and places $\{LS_i\}$, $i=1(1)p_5$.

   These can range across 'individual study areas', 'lecture spaces', 'tutorial rooms' to 'industrial on-site places', 'design offices' or 'virtual worlds'.
6. Institutional or professional outcome standards that can be expressed in multiple levels (e.g. primary, secondary) $\{P_i, S_j\}$, $i=1(1)n_3$, $j=1(1)m_2$.

   These could include the AQF categories (AQF 2012), Engineers Australia (EA 2012), Washington Accord (WA 2012) statements of graduate competencies.
7. Statement of learning outcomes $\{LO_{i,j}\}$, i= learning module, j=outcome.

The description of the LO syntax is dealt with in the next section.



Knowledge, Skills and Application domains

Belongs to: Dynamics and modelling

After: Constitutive relations

<<Topic>>

Name: Lumped parameter systems ☐ clone

Short name: Lumped parameter systems

Key concept: lumped systems ☐ Threshold concept

Description: Models that represent systems where there is the assumption that state values are not a function of spatial position. In these systems we can lump the spatially defined states into one representative state. These models are typical of homogeneous, well-mixed systems.

Knowledge taxonomies and descriptions

Figure 1 Defining knowledge and skills domains

Building curricula

In building curricula there are a number of key activities, principal of which is the description of learning outcomes.

The syntax can be described by a hextuple:

$LO_{i,j}$ ≡ <attainment level><knowledge/skill><complexity><context><learning activity><learning assessment>, for learning module i, with learning outcome j.

For example, the above syntax can be expressed in a specific instance as:

$LO_{i,1}$ ≡ Able to<apply><linear algebra analysis>in<well-defined><engineering systems>through<project work>and assessed by<an individual project report>,

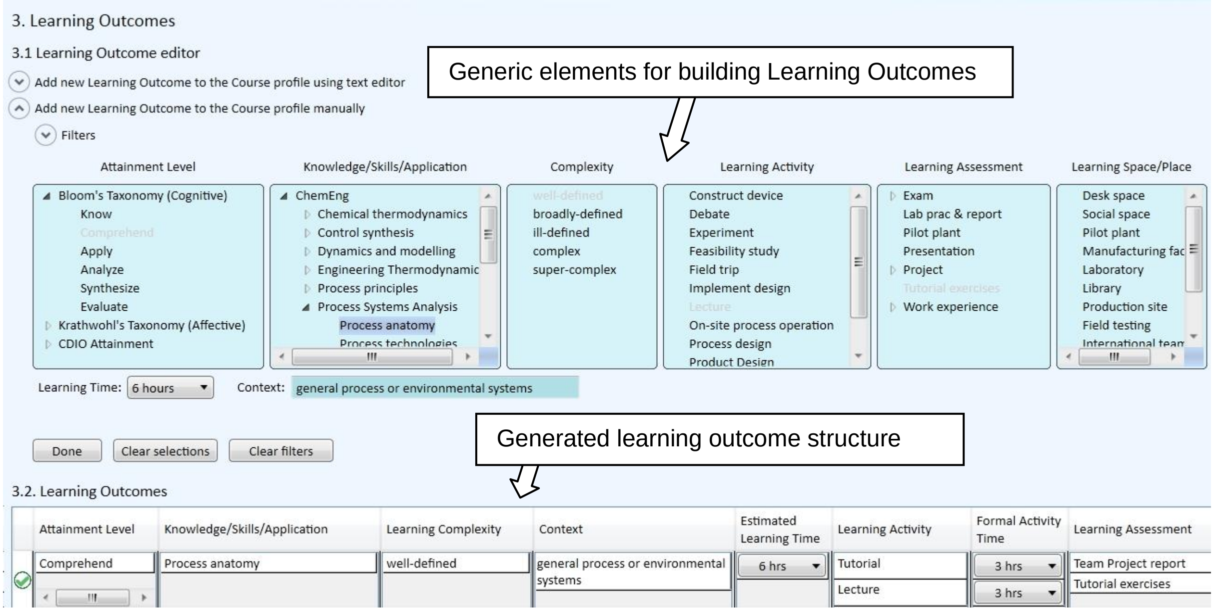
being the first learning outcome associated with the i^{th} learning module,

and

linked to the LO is a description of the <learning activity> and the <learning assessment> with <estimated learning time> and <formal activity time>.

Figure 2 shows how the LOs can be constructed interactively within the environment. Generic knowledge elements are available and selectable to help generate the LO structure. Once selected, the generated LO is then committed to the Learning Outcomes table that is at the bottom of Figure 2. A list of all the LOs for the learning module can then be generated in natural language form, such as:

"1. Ability to comprehend process anatomy for well-defined general process or environmental systems".



3. Learning Outcomes

3.1 Learning Outcome editor

Generic elements for building Learning Outcomes

Learning Time: 6 hours
Context: general process or environmental systems

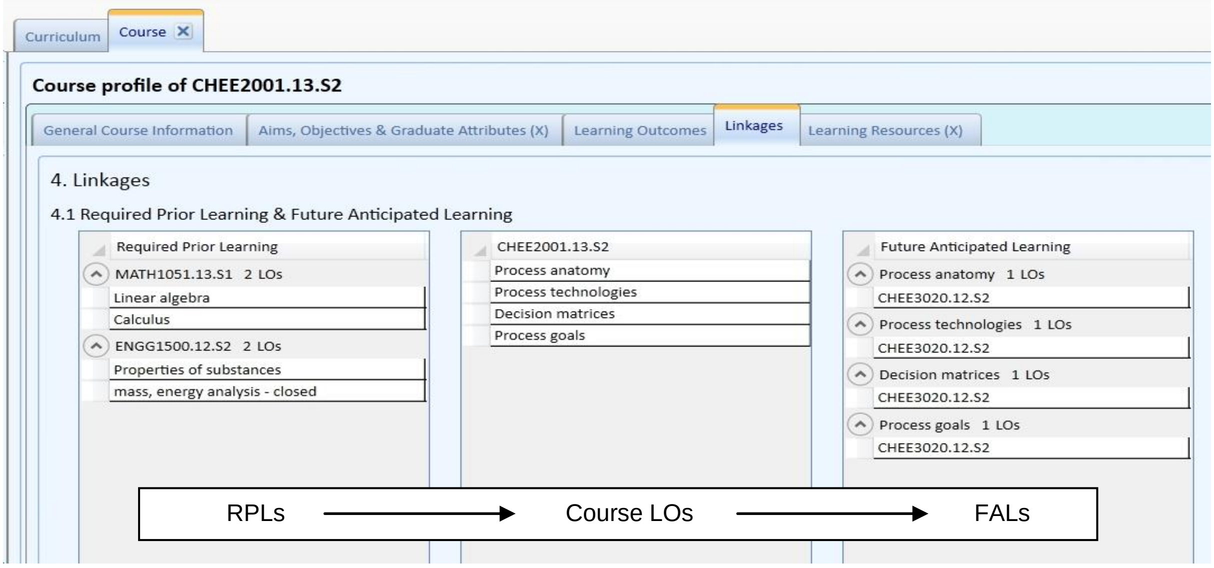
Generated learning outcome structure

3.2. Learning Outcomes

Attainment Level	Knowledge/Skills/Application	Learning Complexity	Context	Estimated Learning Time	Learning Activity	Formal Activity Time	Learning Assessment
Comprehend	Process anatomy	well-defined	general process or environmental systems	6 hrs	Tutorial	3 hrs	Team Project report
					Lecture	3 hrs	Tutorial exercises

Figure 2 Building learning outcomes for a module within a program

Other important building tasks include the construction and display of learning pathways. This permits the linking of knowledge/skills through the curriculum using the concepts of Required Prior Learning (RPL) and Future Anticipated Learning (FAL).



Course profile of CHEE2001.13.S2

4. Linkages

4.1 Required Prior Learning & Future Anticipated Learning

Required Prior Learning
MATH1051.13.S1 2 LOs
Linear algebra
Calculus
ENGG1500.12.S2 2 LOs
Properties of substances
mass, energy analysis - closed

CHEE2001.13.S2
Process anatomy
Process technologies
Decision matrices
Process goals

Future Anticipated Learning
Process anatomy 1 LOs
CHEE3020.12.S2
Process technologies 1 LOs
CHEE3020.12.S2
Decision matrices 1 LOs
CHEE3020.12.S2
Process goals 1 LOs
CHEE3020.12.S2

RPLs → Course LOs → FALs

Figure 3 Building knowledge domain links and pathways

Figure 3 shows an example of how that is currently achieved and Figure 4 displays pathways for interconnected knowledge domains in a curriculum.

These aspects reflect some of the current functionality of the environment. The ability to produce standard displays of various LO characteristics such as the progression of attainment levels across semesters or time, or display the development of a specific skill, such as teamwork are easily done.

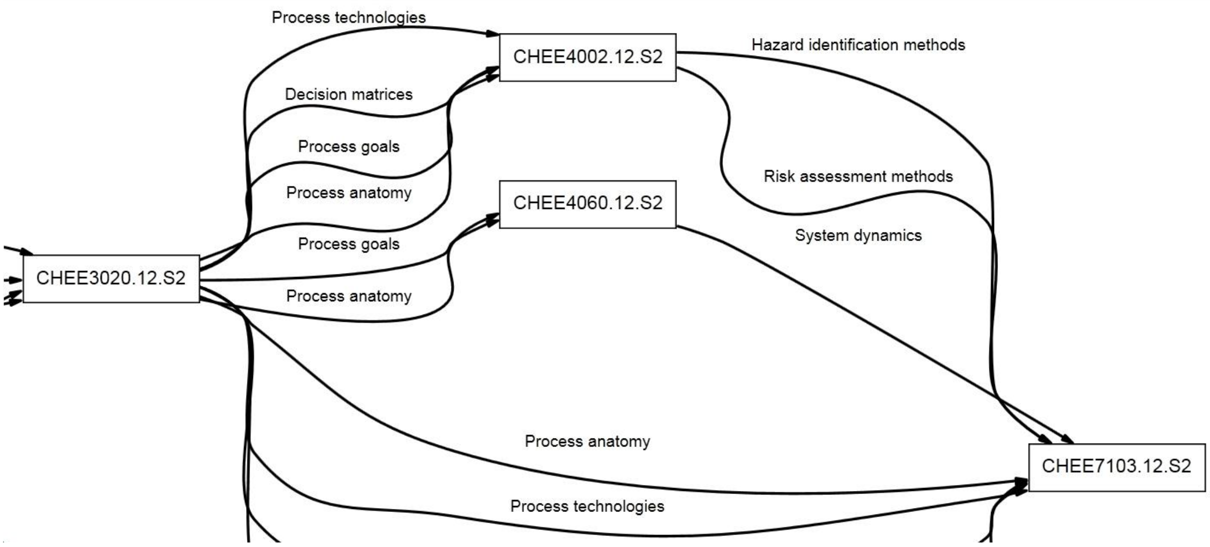


Figure 4 Tracking knowledge domains across years and learning modules (excerpt)

The ability to relate course LOs to graduate attributes or competencies can be achieved. The ability to visualize learning pathways is a power device for a number of reasons. These include the identification of gaps in knowledge areas, duplication issues, sequencing of learning and observation by individual academics just how their engagement in the curriculum occurs and the important links via pathways.

The power for students in engaging with the curriculum is also significant, as visualization of planned or personalized curriculum can display a range of important information to students for decision making purposes within their personalized curriculum selections.

Conclusions and future developments

The prototype environment has been developed with many major components embedded, debugged and tested. Early application of the environment has been done with Chemical Engineering and with School of Psychology being part of the development discussions. The Faculty of Science is now involved in using the environment within a non-professional discipline. Further testing, extension and deployment is required to exercise the initial concepts, but the prototype has provided a solid basis for the way forward.

Of significant importance is the ease by which users can develop structured LOs and generate a range of insights through visualization facilities in the environment. Currently, usability studies are testing these issues.

There are however some important developments to help move this environment more towards a fully functioning design tool where design could be facilitated using generative design approaches (Gruber & Russell 1996) or other design paradigms. These design approaches could generate interesting curricula alternatives that have equivalent expected outcomes or functionality.

The access to such a system for multiple stakeholders could prove a powerful driver for fostering deeper insights for improved decision making around curriculum and course changes. Use by students could help provide information on learning pathways and may provide a tool to track personal curriculum journeys, including performance against curriculum expectations.

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