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An ontological approach to chemical engineering curriculum development

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ABSTRACT

Continuous reflection and evolution of curricula in chemical engineering is beneficial for adaptation to evolving industries and technologies and for improving student experience. To this end it was necessary to develop a method to enable a holistic reflection on the curriculum and to examine potential areas of improvement and change. The curriculum was modelled using knowledge modelling through the development of an ontology, Chemical Engineering Education Ontology (ChEEdO) in the Protégé 3.5 environment. ChEEdO models topics, taught modules and the learning outcomes of the modules within the domain of chemical engineering. The learning outcomes were related to the topics using verb properties from Bloom's taxonomy and the context of each learning outcome. The functionality of semantic reasoning via the ontology was demonstrated with a case study. The modelling results showed that the ontology could be successfully utilised for curriculum development, horizontal and vertical integration and to identify appropriate pre-requisite learning.

1. Introduction: knowledge modelling in education

Knowledge modelling features in curriculum development historically in the form of ontologies, as well as concept maps. Conceptual curriculum mapping was used as a tool to develop and validate engineering curricula based on the program outcomes (Morsi et al., 2007) with proven benefits of facilitating validation, enabling student and teacher conceptualisation of the course, and improving quality and alignment. Similarly, concept maps were used for curricula in school education, which encouraged alignment, integration and communication amongst teachers and are still used in the UK high school education (Koppang, 2004). Whilst concept mapping is a valid tool for knowledge modelling for curricula, we argue that the additional use of properties, restrictions and inferences in ontology engineering provides more scope to probe and interrogate the curriculum structure.

The term ontology originates from philosophy and it is the explanation (λόγοζ – logos) of being (ον – on); today it is used in computer science and knowledge engineering. The most common definition in literature has been coined by Struder et al. (Struder et al., 1998) which builds on previous definitions by Uschold and Gruninger (Uschold and Gruninger, 1996) and Gruber (Gruber, 1993), among others, who define ontology as "*a formal explicit specification of a shared conceptualisation*". Formal means that it is machine readable. Explicit specification refers to the explicitly defined concepts, properties, restrictions and instances of the ontology. The term shared acknowledges that the described knowledge must be commonly accepted by a group of people. Finally, the term conceptualisation is by definition an abstract model of some phenomenon. In simpler terms, an ontology is a knowledge model that contains a group of concepts/terms that describe a specific domain, and more importantly, which is machine processable (Trokanas et al., 2014). These concepts are organised in a taxonomy associated through class-subclass relations (*isA*), and characterised by properties and domain specific relations among them. Relationships and properties are restricted using axioms which allow for inference capabilities (Raafat et al., 2013). An ontology is completed with the use of instances which represent specific entities of the domain.

Within high school curricula in the UK, an ontology for the description of the terminology was developed and enables organisation of learning resources and content discovery (BBC, 2015). Ontology engineering in higher education curricula has been used for various applications such as managing complexity (Dexter and Davies 2009), curriculum development (Cassel et al., 2008), improving resources (Gašević and Hatala, 2006), curriculum review (Ronchetti and Sant, 2007), and content sequencing (Chi, 2009). Some capabilities of knowledge systems in the domain of curricula are: discovery and separation/extraction of foundation material from more complex material, validation of a program, assess-

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ment alignment and validation, change management/curriculum development, supporting consultation and collaboration, a decision making tool, and relationship inferences such as horizontal and vertical alignment. This paper aims to demonstrate the viability of knowledge based modelling to support decisions related to the development and review of chemical engineering curricula based on the curriculum for Chemical Engineering at the University of Surrey. As at present and without intention to limit the scope, the functionality of the ontology is demonstrated in reference to identifying: horizontal integration, and the potential for inter-module assessments; evaluation of vertical integration, and appropriate pre-requisite learning; contextualisation of material, with respect to later learning; and, assisting with decisions about developing new material in the curricula.

2. Methodology: development of ChEEdO

2.1. Curriculum development strategy

Chemical engineering is an applied discipline that brings together different scientific concepts under the same context. Generally, chemical engineering curricula follow a modular structure with progression from either year to year or from semester to semester. Each module comes with a set of learning outcomes, which have to be achieved for the module to be passed. As a student progresses through their chemical engineering degree there are core concepts that are expected to be covered by industry and to achieve accreditation (Gomes et al., 2006; IChemE, 2011). Core and specialist streams within chemical engineering require a progression-like education, i.e. the sequence of topics in chemical engineering is important as fundamental concepts learnt in earlier years are built upon in later years. To this end, students benefit from obvious vertical integration within their curriculum that is a clear link between current and prior learning (Gomes et al., 2006).

In addition to vertical integration, horizontal integration in the curricula is beneficial to the student learning experience. Due to the modularised nature of the degree, students are often unable to see the connections between different topics and, consequently, the curriculum lacks integration throughout the degree program. In order to exemplify these connections, horizontal integration has been suggested as a technique to alter the student perception (Abbas and Romagnoli, 2007). In its simplest form this can be done by setting a single piece of coursework that relates to two or more concurrent modules. In addition, staff engagement effort can be reduced by concomitantly reduced assessment using single assessment pieces across modules. Hence, horizontal integration is able to reduce staff workload and create a deeper student learning experience which, in turn, is beneficial in curriculum development (Abbas and Romagnoli, 2007).

As evident (Byrne 2006), chemical engineering graduates can now be found in highly specialist areas such as molecular engineering, nanotechnology and microelectronics. To further develop the curriculum, introduction of concepts at higher levels within the degree program or addition of specialisation is becoming ever more desirable. Specialisation options are often geo-specific and may be reflected in the expertise and research interests of the staff teaching the degree (Gomes et al., 2006). In terms of teaching efficacy it is often best to align teachers with fields of expertise in order to maintain enthusiasm, which assists in student motivation (Patrick et al., 2000). Developing material at a modular level, however, requires an in depth knowledge of the content within a curriculum across the degree program. New material should then be placed in the context of prior learning to enable constructive learning.

Over the years chemical engineering has changed from the traditional core concepts to the inclusion of a broader range of concepts. Nowadays, chemical engineers are expected to acquire a certain skill set related to the profession (Rugarcia et al., 2000) as reflected in the accreditation requirements (IChemE, 2011). In addition, constant evolution of industry and technology require alternative skill sets to the traditional chemical engineering degree program. However, the program still requires core material to be embedded within the curriculum. In order to reflect and develop a curriculum, core material should be identifiable and learning material and skills placed in the context of later application.

Constant evolution of teaching methods, industry, technology and graduate requirements mean that curricula are continuously evolving. In order to develop a curriculum to meet these changes an in-depth knowledge of the current curriculum is required. Horizontal and vertical integration requires knowledge of the learning topics and contexts in other modules in the degree program. Then, the addition of new material in later years requires knowledge of prior learning in previous semesters and years. Similarly, the student should be able to place their current learning in the context of application or later learning and core learning material should be identifiable. The knowledge required on the curriculum is vast and it is not practical for teachers to retain as the curricula is also evolving. Therefore, a knowledge model in the form of an ontology is proposed to reflect the curriculum and to assist in decision making regarding curriculum development. A modelling approach allows for facile integration and contextualisation of learning and provides a tool to inform learners and teachers about curriculum content. To this end, ontology is designed to model the knowledge contained within the curriculum for chemical engineering.

The knowledge about the curriculum structure, taught modules, topics of learning and learning outcomes are modelled using the module descriptors. The module descriptors contain learning outcomes which utilise Bloom's taxonomy (Bloom 1956) and follow the structure as defined by Biggs (Biggs and Tang 2011). This means that each learning outcome has a learning verb that defines the learning level reflected in the six learning levels defined by Bloom, namely: knowledge, comprehension, application, evaluation and synthesis. Then, the learning outcomes consist of learning topic and context, which, together with the learning level, formulate the specification of learning. Learning outcomes are designed such that assessment reflects the achievement of these outcomes. Hence, they form a basis of the prescribed learning within the degree program and are subsequently chosen as the basis of knowledge modelling in the ontology formulation. The context and topic of learning exist within a taxonomy of topics that are also modelled. The topics are related to each other in consideration of prerequisite learning and subsections of larger topics.

2.2. Ontology implementation

The three high level classes or concepts of the ontology are: *Module* containing instances $\left\{s_i^M\right\}_{i=1}^{n_M}$ representing modules, *LearningOutcome* containing instances $\left\{s_i^L\right\}_{i=1}^{n_L}$ representing learning outcomes and *Topic* containing instances $\left\{s_i^M\right\}_{i=1}^{n_M}$ representing topics, as shown in Fig. 1. For a full explanation of the ontology formulation, please refer to Appendix A. Here and further in this

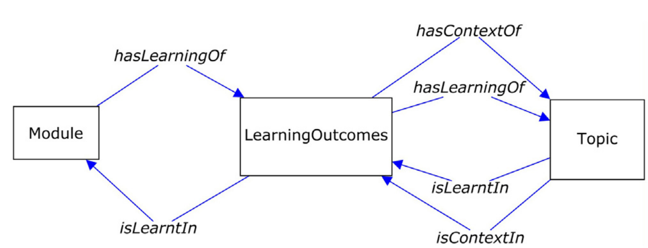

Fig. 1. The high level structure of ChEEdO.