DEVELOPING LEARNING MATERIALS USING AN ONTOLOGY OF MATHEMATICAL LOGIC

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ABSTRACT

Ontologies describe a body of knowledge and give formal structure to a domain by describing concepts and their relationships. The construction of an ontology provides an opportunity to develop a shared understanding and a consistent vocabulary to be used for a given activity. This paper describes the construction of an ontology for an area of mathematical logic as part of an EU Lifelong Learning project and on-going work exploring how this ontology has been used to inform the development of learning resources and appropriate structuring mechanisms. Finally, the paper discusses future work developing enhancements to a virtual learning environment to allow better integration between domain ontologies and on-line courses.

KEYWORDS

Ontology, mathematical logic, learning materials, Moodle

1. INTRODUCTION

The on-line delivery of learning materials is rapidly becoming an important tool in school and university education programmes. Virtual learning environments afford new opportunities in course structures and delivery formats. Pedagogical practice is undergoing a transition as new delivery mechanisms are integrated into existing course structures. These learning technologies provide interesting opportunities to develop new strategies for the delivery of learning materials to students. Many universities and schools now use virtual learning environments (VLEs) such as Moodle (Dougiamas and Taylor, 2003) and Blackboard (Bradford et. al, 2007) as a mechanism to collect together learning activities. However, the adaptive functionality in these environments can only be exploited if sufficient information is known about domain to develop suitably interesting learning paths.

In an era of increasing school and university class sizes, identifying learning paths for individual students can be challenging due to time and resource constraints. The authors are part of the MALog project, an EU-funded project that is working to develop open learning resources to improve mathematical logic knowledge and skills. Mathematical logic is an umbrella term covering a branch of mathematics that includes topics such as set theory, propositional logic, predicate logic and proof. These topics are seen as fundamental to developing knowledge and skills used in many scientific, mathematical and engineering disciplines. Yet developing resources suitable for delivery in the wide variety of learning environments and educational systems found throughout Europe presents some difficulties. The problems include identifying key concepts and their relationships, identifying the specific skills required, and recognising the differences in terminology and educational approaches. Collecting and recording this information in a useful format is a first step to developing better learning resources.

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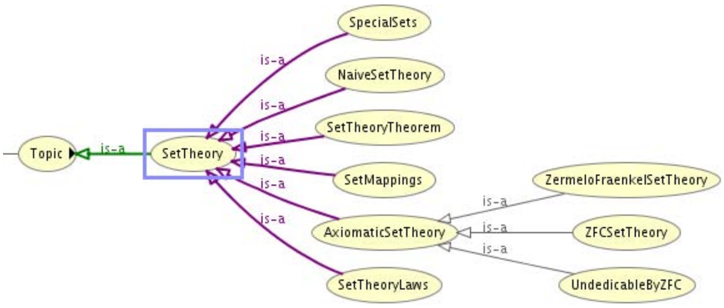

Figure 1. Ontology classes representing set theory topics.

Building an ontology of a knowledge domain allows a shared representation of concepts and their relationships to be explored. When the knowledge domain (in this case mathematical logic) is described with an appropriate level of detail, the information can be useful enough to inform the structure and content of appropriate learning resources. Furthermore, the information gathered can be used to develop learning paths suitable for students with a range of abilities and educational backgrounds. The approach taken here has been to develop an ontology of mathematical logic which identifies key mathematical concepts, mathematical topic areas and prerequisite information.

The aim of this project is to use the information gathered in the ontology of mathematical logic to develop a suitable course structure. Assessing existing knowledge and providing suitable remedial support is vital to successful learning (Fensham, 1972). An individual learning path will be appropriate to the needs of the student by accounting for their individual learning style and rate of progress. By identifying problematic concepts, the adaptive functionality found in many VLEs can be exploited to produce learning paths where material is automatically recommended to students based on their progress through learning materials. This paper describes the construction of an ontology in the area of mathematical logic and describes on-going work that uses this ontology to develop and structure educational resources appropriate for a range of students.

2. ONTOLOGIES AND LEARNING

An ontology provides a mechanism to formally represent a body of knowledge. One of the earliest definitions of ontologies (as used in information science) is the "specification of a conceptualization" (Gruber, 1995). Ontologies have since developed into an important technology of the Semantic Web (Berners-Lee, 2001), adding machine recognisable meta-data to information available on the World Wide Web and providing new opportunities in data processing, sharing and reasoning. Technologies such as RDF and the Web Ontology Language (OWL) have supported the development of the Semantic Web and emphasised the importance of the ontology concept. Outside information science, the medical science community have developed numerous examples of ontologies covering human, plant and animal biology demonstrating how large vocabularies can be successfully developed, used and further explored.

In a learning context, an ontology can be used to formally describe a set of concepts (or topics) and the relationships between these concepts. A domain ontology can be used to describe an agreed organisation of concepts and a shared vocabulary which can be used to ensure consistent use of technical terms. An ontology can provide students with a mediating artefact to aid understanding of the structure and vocabulary of a domain. Henze et. al. (2004) demonstrate how ontologies can be used to personalise e-Learning material and recent work by Laroussi (2012) describes how ontologies can be used to model user behaviour in adaptive learning environments. The MALog project has been developing an ontology to provide a description of the topics in the mathematical sub-field of mathematical logic. The ontology has been constructed from a detailed survey of mathematical logic textbooks, Internet resources and other material to identify specific concepts and topics. Key words and phrases have been identified and organised into categories, first more general and then categories with increasing specificity. High level categories became entities within the ontology class hierarchy (e.g. 'set theory', 'axiomatic set theory') and specific concepts within those areas have been created as individuals within the ontology and classified under one or more ontology classes. Figure 1 shows an example of this hierarchy. As part of the process, information about the relationships between specific concepts has also been recorded within the ontology. Related topics are linked, similar concepts from different sub-fields are identified and mathematical symbols are connected to concepts. Production of the ontology is the result of a negotiation of meaning of the domain of mathematical logic. Further information on the strategy used for developing the ontology is described in Boyatt and Joy (2010).

3. ONTOLOGIES AND LEARNING MATERIAL DEVELOPMENT

The construction of the ontology is motivated by the desire to identify the mathematical logic topics and relationships between these topics suitable for inclusion in a set of related learning materials. The ontology is used as the semantic foundation giving an initial structure to the development of learning materials. The initial version of the ontology identified over 500 concepts (as ontology individuals) and 60 categories and sub-categories (recorded as ontology classes). The ontology information was then used to develop units of material on mathematical logic topics. The categories provided learning material authors with initial suggestions for how to structure units of material. The concepts (individuals) within each category (class) immediately provides a list of concepts to be included within a unit of learning material. For example, the ‘NaiveSetTheory’ class included concepts such as ‘Set_Union’, ‘Set_Intersection and ‘Set_Membership’ suggesting a unit of material covering naïve set theory. For many topics it was easy to identify specific concepts but for some topics this process exposed differences in educational systems for how concepts should be organised and related. Explicitly enumerating mathematical concepts in the ontology also ensured concepts were not missed or duplicated inappropriately in the learning materials. Additional information stored such as related concepts and mathematical symbols could also be accessed by the material authors.

The MALog project is a collaborative project between several European countries requiring the development of material in five different languages. Ensuring consistent use of mathematical terminology has been aided considerably by the shared vocabulary and representation of knowledge stored in the ontology. The shared artefact has ensured that learning material has been developed with consistent use of terminology. Consistent use of terms has reduced the possibility of learners becoming confused with similar mathematical concepts. Recording the reuse of terms has also allowed us to provide navigation aids to learners by allowing them to identify all instances of specific concepts, e.g. allowing a learner to find all instances of the concept 'Cardinality' within the material. This mechanism has been provided by developing software to read the OWL ontology file and display information within Moodle listing concepts related to the current activity.

Other mathematical ontologies such as GeoSkills ontology developed by the I2Geo project identified specific competencies that learners can hold (Libbrecht et. al, 2008). These competencies connect together different topics to represent a particular understanding that should be held by the learner. This approach has been adopted for the mathematical logic ontology identifying competencies for three categories of learner: high-school students, university undergraduate students and industry workers. Over 100 competencies have been identified for each of these class of learners and are represented in the ontology in the 'Comptency' class. For example, the 'Create_truth_table_for_NAND' relates the concepts (ontology individuals) for 'AND' and 'NOT'. For the learner material author, the competencies provide a structure to units of learning materials and help build a basic structure of conceptual prerequisites. We are developing software that reads the entities from the OWL ontology file (using the Apache Jena API) and creates activities within Moodle that relate to each competency. Activities are ordered appropriately within the environment (using the limited adaptive functionality available) to ensure that students encounter material about 'AND' and 'NOT' before learning specifically about 'NAND'. The student using the ontology information can use the information to identify their attainment level and the competencies they should understand. Quizzes that test specific competencies are created ready for learning material authors to insert suitable questions that would enable the next set of material within the environment.

4. FUTURE WORK

This paper describes work in progress developing and using an ontology of mathematical logic to produce learning materials and structure this material in a manner appropriate for use by students in schools, universities and industry. Undoubtedly the ontology of mathematical logic will continue to develop and be enhanced as it is used to inform the development of further learning materials. We expect the ontology to be enhanced with additional vocabulary, additional languages and cultural terms using strategies such as those developed by Espinoza (2008) and new connections formed between topics. Nevertheless, the ontology has reached a sufficient level of maturity to be useful to practitioners. The current approach is for the ontology to inform the construction of courses within our virtual learning environment. Courses are mostly manually constructed using the information gathered ontology editor view of the ontology (see Figure 1). On-going work is to further develop plug-in functionality for the Moodle VLE to create a basic course structure. We intend for activities in Moodle to be related to specific competency individuals from the ontology and learning materials to be related to specific topic individuals.

5. CONCLUSION

This paper has described a strategy for developing learning materials and structuring the delivery of that material using information collected in an ontology. While the work described is on-going, it shows the advantages of collecting domain information with an ontology to agree consistent use of vocabulary across a project involving multiple languages and providing a structure to develop learning resources appropriate for a broad range of learning environments.

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