Educational Ontology and Knowledge Testing

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Abstract: The Bologna declaration aims at providing solutions for the problems and challenges of European Higher Education. One of its main goals is the introduction of a common framework of transparent and comparable degrees that ensures the recognition of knowledge and qualifications of citizens all across the European Union. This paper will discuss an ontology-based model that supports the creation of transparent curricula content (Educational Ontology) and the promotion of reliable knowledge testing (Adaptive Knowledge Testing System). Beside the description of the evolution of the Educational Ontology, which has been developed within a research project by the Department of Information Systems, role of the ontology in managing, mapping and sharing the knowledge of curricula will be discussed in details as well. The Educational Ontology addresses establishing relation between the requirements of labour markets and the content of curricula through competencies that can be acquired during a given training program. Another critical aspect of this research concerns the measuring of knowledge. The second part of the paper will focus on the possibilities of adaptive knowledge testing and describes how a suitably elaborated ontology model can support adaptive testing of students by enabling a detailed exploration of missing knowledge and knowledge areas.

Keywords: knowledge representation, ontology, adaptive testing

1. Introduction

The Sorbonne Joint Declaration of 25th of May 1998 was the first one, which proposed the creation of the European area of higher education as a key way to promote citizen's mobility and employability and Continents overall development. The Bologna declaration (1999) acknowledged the importance of these statements and initiated remarkable reforms of European Higher Education, also recognising its crucial role in social, economic and human growth of the Continent. Beside the creation of the European Higher Education Area, the Bologna process aims at:

- Adapting easily readable and comparable degrees,
- Adapting a system essentially based on two main cycles,
- Establishing a system of credits,
- Promoting mobility,
- Promoting European co-operation in quality assurance and
- Promoting the necessary European dimensions in higher education.

The goal of introducing a common framework of transparent and comparable degrees that ensures the recognition of knowledge and qualifications of citizens all across the European Union was highlighted again in the Berlin Communiqué (2003), which added a third cycle (doctoral cycle) to the Bologna Process.

> *"Ministers encourage the member States to elaborate a framework of comparable and compatible qualifications for their higher education systems, which should seek to describe qualifications in terms of workload, level, learning outcomes, competences and profile."*

The members of the Joint Quality Initiative aimed at developing descriptors for Bachelor's and Master's that might be shared within Europe and be available for a variety of purposes, depending on particular national, regional or institutional contexts and requirements. This was one of the first initiatives, which provided support for facilitating the comparison of degrees. The launch of these Dublin descriptors also indicates that competences should have a key role in providing transparent and comparable curricula and qualifications. Beside the description of the evolution of the Educational Ontology, its role in overcoming still existing obstacles of access between cycles and its role in measuring knowledge in a reliable and objective way will be also discussed in the paper. The European Higher Education Area is structured around three cycles where each level has the function of preparing the student for the labour market, for further competence building and for active citizenship. Accordingly, the demonstrated research aims at providing ontological relation between competencies acquired during a training program and labour market requirements. Preparing the student for the labour market and for further competence building also requires setting up ontological relation between the content of curricula and competences. A further goal of this research is to provide support for adaptive knowledge testing with the help of the Educational Ontology. The curricula of Business Informatics will be described analysed in this research.

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2. Contribution

One major goal of the research is to establish ontological relation between the requirements of labour markets and the content of curricula with the help of competencies that can be acquired during the Business Informatics training program. Accordingly, it must be thoroughly investigated whether it is possible to work out an ontology model that is suitable for modelling the concepts and semantic relations of all the Business Informatics curricula, even despite the fact that these subjects are subsequently different in scope and nature as well. Further objective of the research is to support the adaptive assessment of knowledge acquired by the students, especially in connection with the efficiency of education and detailed exploration of missing knowledge areas. To verify the hypothesis the principles and methods of adaptive examination and solutions for computer-aided testing must be acquainted and analysed and procedure planned to be adopted must be selected too. This requires the determination of the knowledge area to be tested and the expected level of knowledge as well.

The goal of the new adaptive testing system is not only the improvement of efficiency and fastness and the quick announcement of exam results, but to point out those knowledge areas or curriculum parts, where the individual has shortcomings. For proving the hypothesis, the role of Educational Ontology in determining missing knowledge areas and the necessity of classification and structuring of the knowledge base of training must be examined too. Furthermore it must be explained how the ontology can support the construction and operation of the adaptive testing system and the most appropriate solution for connecting the two system must be revealed as well. Keeping these goals in view the following research questions should be analysed and related activities must be accomplished during the course of research:

- How the knowledge of Business Informatics curricula should be structured and modelled?
  - Specification of Business Informatics curricula and competences that can be acquired during the training program and this way must be represented in the ontology
- How the model of the Educational Ontology should be build up?
  - Clarification of the concepts of ontology and its components as the tool of knowledge representation.
  - Analysis of the utilisation domains and application possibilities of ontologies.
  - Analysis of methodologies, selection of a suitable ontology engineering methodology and its customisation
  - Creation of an ontology model that is capable of seizing the common features of different curricula and the definition of basic ontology elements and their relations
  - Analysis of ontology languages, investigation of formalisms that enable the representation of knowledge stored in our ontology
- How the appropriate implementation tools should be chosen?
  - Analysis of requirements related to the implementation tools according to our research goals
  - Mapping of the available ontology development tools
  - Selection or elaboration of the appropriate tools according to the requirements

3. Educational ontology

A challenge of modelling is that the scope of curricula taught in Business Informatics training program is wide and curricula are substantively different in nature. For example the modelling of Knowledge Management curriculum may require different approach, then the modelling of Mathematics. Moreover it should be also taken into consideration that the structure and content of a subject may be at least partly different in different institutions. Accordingly in the first cycle of development the research has concentrated on defining the major classes of the ontology, pointing out the role of competences and concentrating on facilitating comparability.

3.1 Initial ontology model

Competences have played central role in the first version of the ontology model to enable grabbing the common features of different curricula. In higher education, accreditation documents must provide a list of goals of the given training program in the form of competencies. This means that competencies and curricula of the training program must be aligned. Accordingly classes of “Competence module” and “Curricula module” were formed and connected to each other with the “belongs to” relation in the ontology to enable tracing of knowledge and competences possessed by students. Modules represent standardised units (of curricula or competences) that facilitate the comparison of curricula and competences of different institutions and universities. Competencies also have to be aligned with labour market requirements. In this case groups of tasks that are necessary to successfully carry out work duties and the required competencies must be aligned, so in the ontology the class of “Group of tasks” is connected to the class of “Competence Module” with the “required by” relation. Curricula are modelled by defining their major parts that we call knowledge areas. The class of “Knowledge Area” is further structured into elements that are the least knowledge elements; assertions that are set up by assertions, elements and logical rules, which are divided into logical operational symbols and inference rules (like IF-THEN, THEN-IF). This part of the conceptual model ensures the comparison of the curricula’s contents and provides a basis of testing system by enabling inferencing. Figure 1 depicts the initial ontology model.

Creation of ontology and its content always has to be based on consensus and its easy use and understanding also has to be ensured. Although the above described model provides a promising approach for structuring the given domain and offers efficient help in comparing knowledge covered by the curricula of different institutions by applying modules, the actual construction of the ontology – especially the modelling of knowledge areas – would expect enormous efforts from the experts of the field, from the teachers. For that very reason the model requires modifications and improvement, and its connection with adaptive testing system should be elaborated as well.

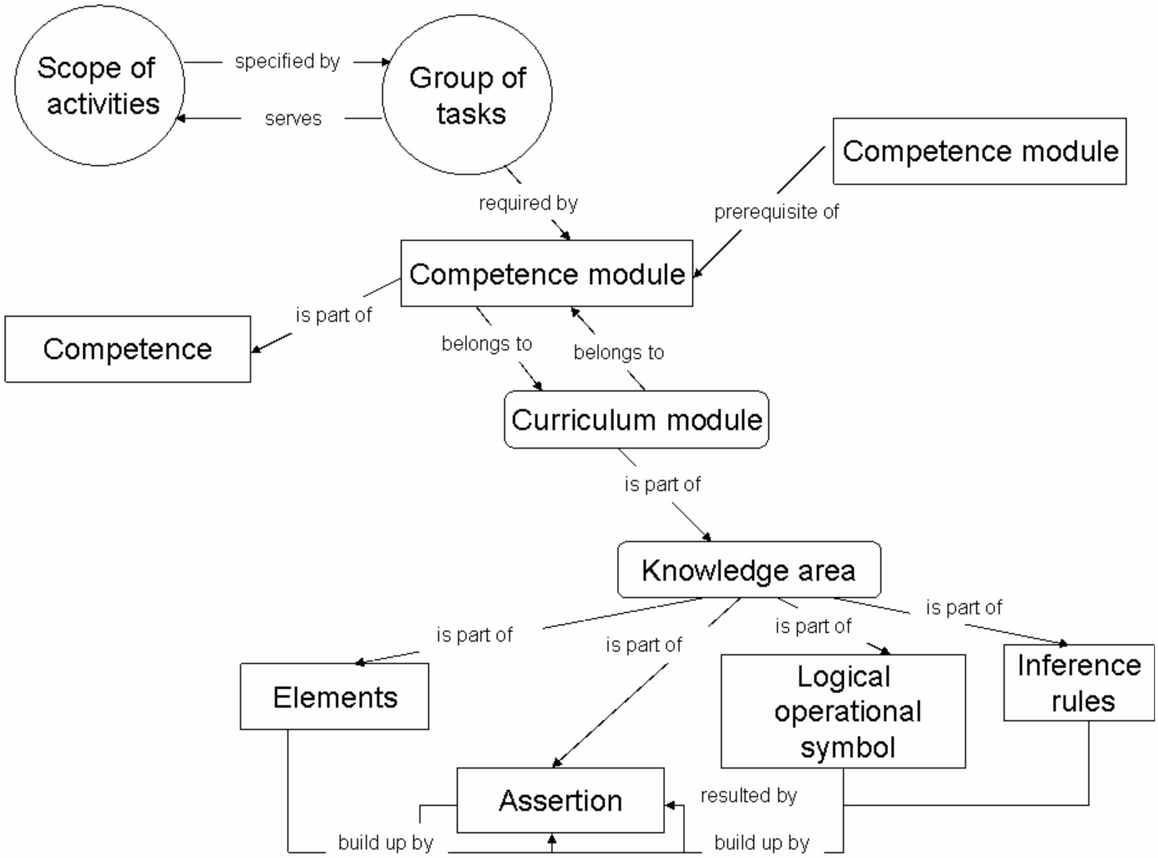

Figure 1: Initial Ontology model

3.2 Improvement of the ontology model

Knowing the amount of work required to produce ontologies even for the simplest concepts, the improvement of the ontology was focused on providing easily definable and applicable classes and precise determination of relations, also keeping the goal of knowledge testing in view. This section gives a description of all ontology classes and the introduced changes too.

3.2.1 Scope of activities

The “Scope of Activities” class contains all of those professions, employments and activities that can be successfully performed with acquisition of those competencies that are provided by the training program.

3.2.2 Group of tasks / competence module

In the first version of the model the “Group of Tasks“ and the “Competence Module” class ensured the connection between the scope of activities and knowledge areas acquired during the training. Taking into account the goals of the research and the above-mentioned problems these classes are too general. Instead the following elements were introduced in the model:

- "Task" and "Competence" class
- One scope of activities should be in direct "*specified by*" – "*served by*" relation with tasks. This way the given scope of activities prescribes a number of concrete tasks and not a group of tasks.
- Each task should be in "*requires*" relation with competences.

This way not sets (competence modules, group of tasks), but their elements are connected to each other. This solution also enables a facilitated execution of comparison and declaration of differences between competence modules. At the same time the "Group of Tasks" and the "Competence Module" classes should be kept in the model to enable the definition of the sets of tasks and competences as well and ensure further ways of comparison.

3.2.3 Curriculum module

In the first model "Knowledge Area" and the "Competence Module" has been connected through the "Curriculum Module". In the modified model knowledge areas and competences are connected indirectly with the "*requires*" and "*ensures*" connection. (A competence *requires* the knowledge of a given knowledge area and the good command of a knowledge area *ensures* the existence of certain competence(s).) The class of "Knowledge Area" is an intersection of the ontology, where the model can be divided into two parts:

- One part of the model describes the relation of knowledge areas and labour market requirements with the help of the above-described elements.
- The other part will depict the internal structure of knowledge areas.

Figure 2 depicts the first part of the model in the following way:

- Rectangles sign classes.
- Arrows depict 0-N relations (so a competence may have several prerequisites, scope of activities may specify more tasks at the same time and it is also possible that a competence those not have any prerequisites).

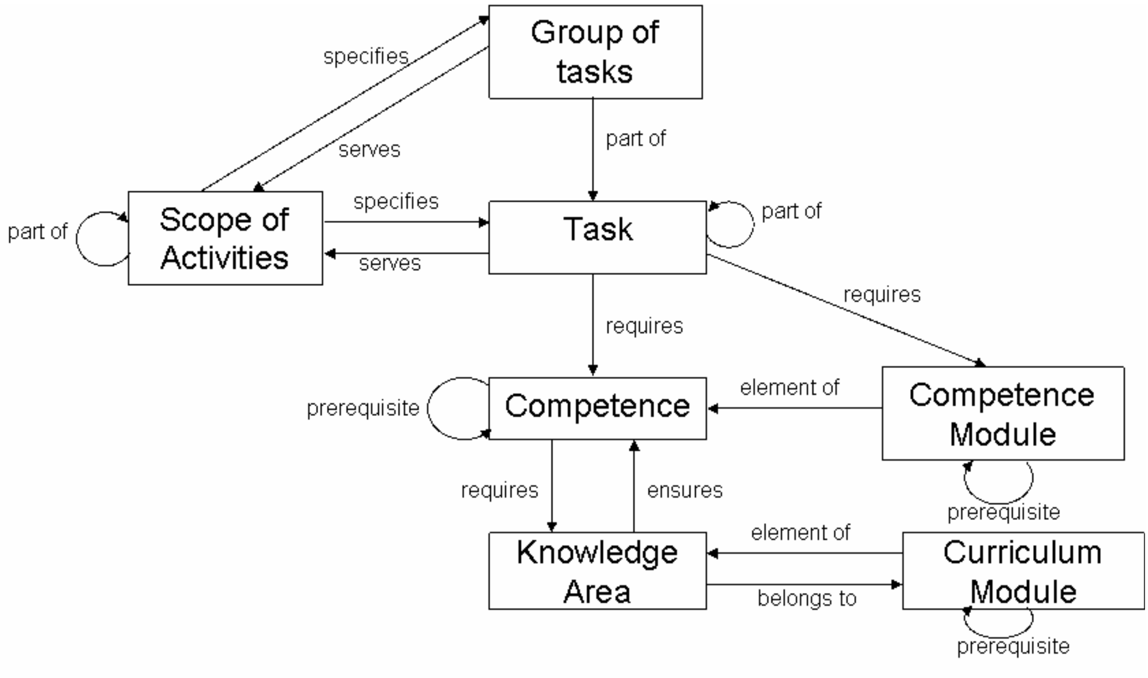

Figure 2: Ontological relation of Knowledge Areas and Scope of Activities

3.2.4 Knowledge areas

In the former model knowledge areas have been divided into basic concepts and sub-knowledge-areas, but the internal structure of knowledge areas must be refined to allow of effective ontology construction and the efficient functioning of the adaptive knowledge testing system. "Knowledge Area" is the superclass of the ontology, representing major parts of a given curriculum. Each "Knowledge Area" may have several "Sub-Knowledge-Areas". Not only the internal relations, but relations connecting different knowledge areas are also important regarding knowledge testing. The "*is part of*" relation is still an important element of the model connecting knowledge areas and sub-knowledge-areas in the model. At the same time a new relation has to be introduced, namely the "*requires* knowledge of" relation. This relation will have an essential role in supporting adaptive testing. If in the course of testing it is revealed that the student has severe deficiencies on a given knowledge area, then it is possible to put questions on those areas that must be learnt in advance.

For the sake of testing all of those elements of knowledge areas are also listed in the ontology about which questions could be put during testing. These objects are called "Knowledge Elements" and they have the following major types: "Basic concepts", "Theorems" and "Examples". The internal structure of knowledge elements is not examined in details. For example we do not conduct precise analysis on how different basic concepts are based on each other. Knowledge elements are only examined from that point of providing support for the adaptive testing. The introduction of this method has practical reasons, since an overall, comprehensive analysis of the internal structure of knowledge elements is enormous and an almost unaccomplishable task. Compared to the thorough analyses of these elements, the simple listing of elements is relatively easy work. Moreover if test questions are connected to each knowledge element, then it also enables the adequate functioning of the testing system. Although, in order to precisely define the internal structure of knowledge areas relations that represent the connection between different knowledge elements also must be described. The role of "premise" and "conclusion" relations is to determine which basic concepts are used to declare a given theorem and which basic concepts are formed by the declaration of a theorem. The "refers to" relation determines connection between knowledge elements of the ontology. Namely, a basic concept or theorem may refer to another basic concept or theorem and an example may refer to any of the other two knowledge elements. The goal of introducing this relation is to enable making connection between knowledge elements, where it is indispensable in ensuring understanding and formation of clear ontology structure. Applying the previously described marking system of Figure 2 the internal structure of knowledge areas can be depicted in the following way (Figure 3.):

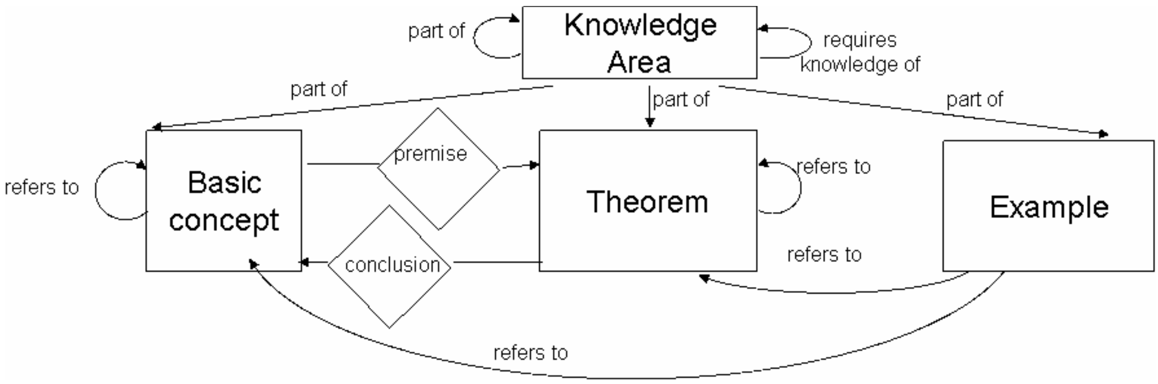

Figure 3: Internal structure of Knowledge Areas

3.2.5 Testbank

In order to provide adequate support by the educational ontology for the testing system several theoretical foundations and conceptions must be laid down in this model. One pillar of the testing system is the set of test questions. Main characteristics of test questions should be the following:

- A question must be connected to one or more Knowledge Elements or Knowledge Areas. On the other hand a Knowledge Element or Knowledge Area may have more then one-test question. The Educational Ontology structures this way the Testbank.
- All questions should be weighted according to their difficulty.
- Test questions will be provided in the form of multiple-choice questions. So parts of the question must be the following:
  - Question
  - Correct answer
  - False answers

Figure 4 shows the entire and final model of the Educational Ontology, also depicting how test questions connect to the elements of the ontology. (Test questions are connected with dashed lines to the ontology, indicating, that they don't form a part of the ontology.)

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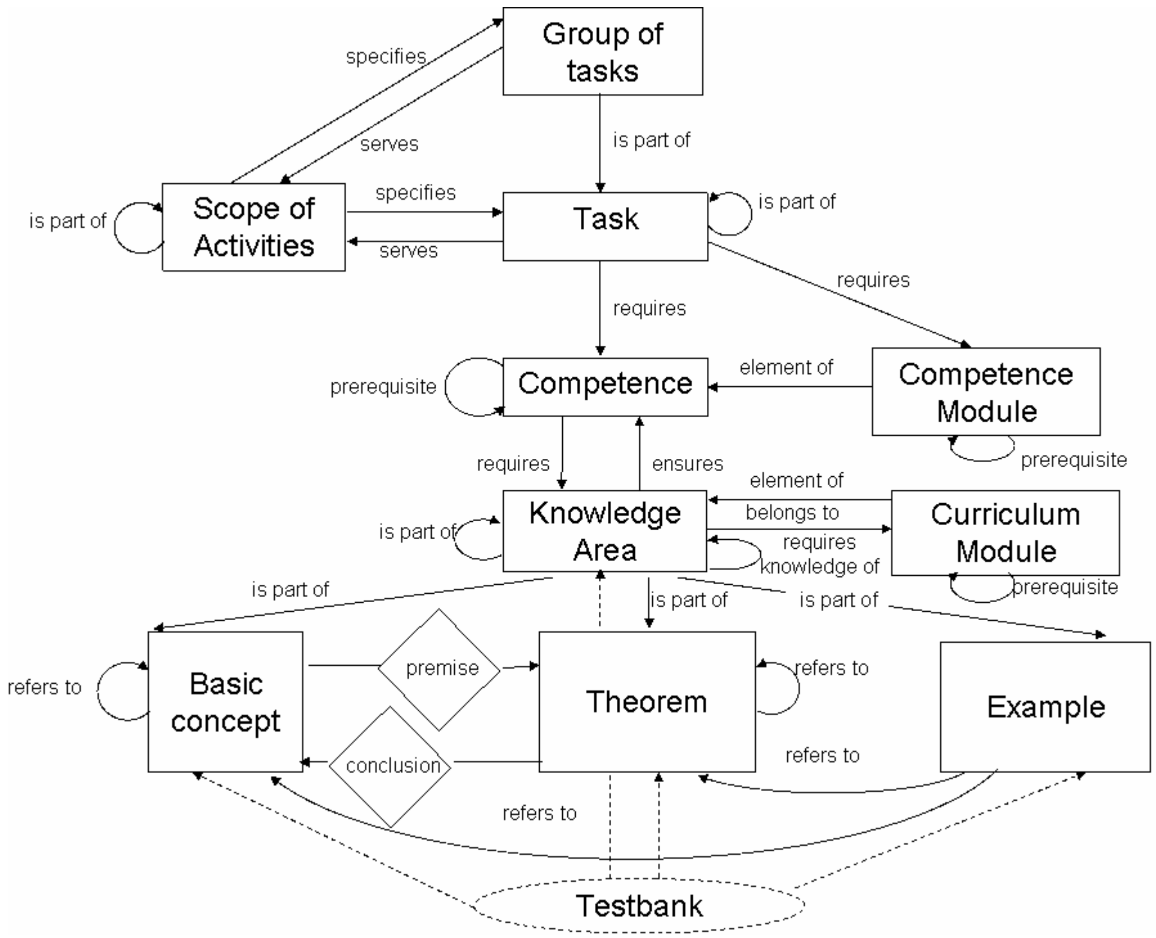

Figure 4: The model of Educational Ontology

4. Adaptive knowledge testing

Primarily, the ontology aims at capturing and modelling all knowledge, which is part of the curricula of Business Informatics program. Besides, a suitably elaborated ontology model can support the (adaptive) knowledge testing of students by enabling a detailed exploration of missing knowledge and knowledge areas (KA). The ontology model is developed as a part of a research project conducted by the Department of Information Systems at the Corvinus University of Budapest, which aims at introducing an interface, which can develop a customised qualification program, based on the individual's pervious qualifications, completed levels, corporate trainings and practical experiences, in case of entering a certain educational level. Two main groups of input are needed to build up a qualification program. On one hand the individual's knowledge and abilities must be measured, on the other hand a definition must be given about the prerequisites of the targeted qualification, which depends on the quality assurance and the accreditation system of higher education. After testing the individual's knowledge, a customised supplementary training program should be allocated. A corresponding adaptive test provides help to the individual, who draws on this service. If the candidate passes the exercises and tests successfully, than the prerequisites for the certain qualification are fulfilled, so the student may enrol to the targeted level. As an additional benefit, some parts of this solution may be used for correcting the deficiencies of a certain curriculum during the qualification, as an ad-hoc support of education. The model itself consists of two main modules: the Test Module, which consists of the Educational Ontology, Testbank; and Adaptive Examination System; and the e-Learning environment, which contains a Learning Management System and a Learning Content Management System. The Educational Ontology plays a key role in setting into operation the Test Module and also has an indirect influence on the functioning of the whole learning environment.

The main principles of adaptive testing also have to be analysed to enable the development of an adequate testing system and its connection with the ontology. The main idea of adaptive testing is that the test should tailor itself to the estimated ability level of test takers and take into account how each test taker has answered previous questions. Accordingly the test taker always encounters personally challenging questions in the test. Alfred Binet (1905) worked out the first form of adaptive testing. In his intelligence test he aimed at making a diagnosis of the individual candidate by the following simple strategy: The test items (questions) were ranked according to their difficulty. He would then start testing the candidate with a set of questions targeted at the estimated level of candidate's ability. If the candidate succeeded, Binet continued to give successively harder questions till the candidate frequently failed and vice-versa. With this strategy Binet could easily define or estimate the real ability level of the candidate. Lord's (1971) Flexilevel Testing Procedure, in which he applied adaptive techniques in test evaluation, is also an important contribution to adaptive testing, just like its variants, such as Hening's Step Procedure or Lewis and Sheehan's Testlets. All of these procedures is easy to implement with computers, but Reckase (1974) was the first who worked out a methodology of computer adaptive testing (CAT) (Linacre 2000). The basic principles of computer adaptive testing are provided by Thiessen and Mislevy (1990):

- Test can be taken anytime, no need of group-administered testing.
- There are no identical tests, as every test is tailored to the needs and capabilities of the test-taker.
- Questions are presented on a computer screen.
- After the answer is confirmed there is no chance to change it.
- The examinee is not allowed to skip any of the questions.
- The questioning process is fully and dynamically controlled.

4.1 Supporting knowledge testing

In the previous section it has been already introduced how test questions are connected to the ontology and how the Educational Ontology structures Testbank. In this section possible ways of applying the Educational Ontology in knowledge testing and other implementation questions are discussed. With the help of the developed ontology we can get answers very easily for several administrative questions. On one hand, the applied structure ensures easy access to all of that information (knowledge areas, competences) that is necessary for conducting a specific task. On the other hand, if a candidate provides information about her/his knowledge, the system is able to define and list all of those tasks and activities that the candidate is able to conduct. Moreover, the combination of the above-mentioned two cases is also possible. If the candidate describes what kind of tasks he wants to conduct (what scope of activities is that he/she wants to do) and the knowledge he/she has, then based on the ontology model it can be laid down which competences he/she still has to acquire. Another important application of the ontology is to provide support for the exploration of missing knowledge areas. Primarily, the goal of examination must be described to be able to define those knowledge areas that are necessary for the fulfilment of those tasks that are related to the defined goals. These knowledge areas must be examined when looking for deficiencies. The tool of exploring missing knowledge is the test. The proposed goal and the ontology determine the scope of test questions in the exam. Based on the distribution of correct and incorrect answers on the structure of the ontology an adequate figure can be drawn about the knowledge and deficiencies of the candidate. In setting up such test the structure of the Educational Ontology and semantic relations among knowledge elements provide efficient support.

4.1.1 Testing procedure

After the elaboration of the ontology the next step of the research was to work out a testing procedure, an algorithm that will define the order of questions and enables adaptively. The testing procedure starts the examination at the top of the hierarchy of knowledge areas. It gives the student a testlet having so many questions that cover the given knowledge area. If he answers properly – vis. the sum of points received for his answers reach a given level (for example 60%) – we put questions about all the basic concepts and all the sub-knowledge-area of this knowledge area. If the student does not know the answer for the question related to the basic concept the knowing of the knowledge area will be refused. If he answers badly for some sub-knowledge-area the knowledge area and these sub-areas will be not accepted, but if there are some sub-knowledge-area whose questions were answered properly then the testing engine interrogate them again in the previous manner. Namely the testing engine executes a depth first graph search algorithm in such manner that it closes a branch if the student does not know the given knowledge area or its sub-knowledge-areas (all of them) or a given basic concept

4.1.2 Questions of implementation

Beside the challenge of developing an ontology model that suits all of the requirements arisen by different curricula, selecting the most appropriate ontology language for formalisation is also a critical aspect of the project. The applied ontology language will also determine the usefulness of the

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reasoning engine. The higher the expressiveness of the ontology language is, the lower will be the number of questions that can be answered with the help of the reasoning engine (Corcho, Gómez-Pérez 2000), (Gómez-Pérez, Corcho 2002). Finally selecting a proper ontology-engineering tool, which is capable of handling even several thousands of concepts and applying the required ontology language is also a critical decision of the project. For the machine readable representation of all the classes and relations defined in the Educational Ontology the application of OWL DL ontology language is proved to be an adequate solution. From the wide range of existing ontology editing tools we have chosen Protégé2000 that is the most known and widely applied open-source ontology editor capable of handling OWL ontologies. The Testbank has also been built into the Protégé system and finally a Java software was developed that runs the program of adaptive testing.

5. Conclusions

In the current phase of the research curricula of the Business Informatics program are modelled and uploaded to the Educational Ontology and several students have already tested the adaptive knowledge testing system as well. The primary goal of the adaptive knowledge testing system, which is supported by the Educational Ontology, is to explore missing knowledge areas. At the same with the help of the ontology the accumulation of acquired competences and knowledge can also be determined. This way employers will be able to reinforce the position of student, trainee and employee when these persons want to enter in the labour market, want to look for another job or continue their study. In the future by improving the ontology and extending its content a common understanding of levels of competences based on learning outcomes can be established and this way educational systems can compare their positions. Qualifications of "higher" level embrace the competences of "lower" levels. This suggests that there is a hierarchy between competences. Improving the model and applying further relations can also model this hierarchy in the Educational Ontology.

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