Procedural Knowledge Representation in Learning Management System

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Abstract: Current e-learning systems are focused on the transfer of static knowledge (definitions, descriptions, explanations, theories etc.), to the detriment of supporting the internalization of procedural knowledge, scenarios, and problem solving practices and to enabling students to construct heuristics. The fixed multimedia pages, used in learning management systems like WebCT, are not the most suitable mean for passing on procedural knowledge, and commonly used multiple-choice tests are hard to be defined with the aim to evaluate student’s level of procedural knowledge, not only outputs of its application. The purpose of the paper is to analyze the possibilities of teaching and learning procedural knowledge in relation to the research results in the field of knowledge representation and processing, especially for the case of teaching higher mathematics through modern e-learning technologies. We discuss the ways of stimulation students’ thinking, context interpretation, problem-solving technique selection and application by exposing the students to under-defined or partially specified tasks in e-courses of mathematics.

Keywords: procedural knowledge, knowledge representation, university education, learning management system, higher mathematics

1. Introduction

The knowledge society needs flexible workers who are able to adapt into new conditions and willing to learn and, if necessary, to change their qualification during the life. With respect to the newly coming social requirements, two main needs of learners arise, independently on the type and level of education:

- the need to orientate oneself in data, information and knowledge resources, whose amount grows continuously and which is ever easier accessible thanks to modern information technologies, especially internet,
- the need to master knowledge of procedural type, i.e. to internalize procedures, guidelines, scenarios, algorithms and to develop heuristics. Fact-based knowledge is within the grasp thanks to digital technologies, but is beneficial only in the case that the person can use information and knowledge resources effectively and he or she masters problem solving methods based on the application of these resources.

The most common e-learning solution is learning management system (e-learning study environment, systems for management of education), that are used – in terminology of knowledge engineering – mainly for providing static knowledge, when students can learn theories, sets of concepts, facts, relations and rules. For this purpose, e-learning environments offer numerous functionalities, developed for providing static knowledge (such as content modules, glossaries, indices, multimedia databases, tests, quizzes providing the feedback to students etc.). The providing of knowledge of procedural nature, i.e. knowledge of procedures (sequences of steps), typical scenarios, algorithms and heuristics, is not supported by so many tools and functions of learning management systems. In general, teaching of procedural knowledge, especially of heuristics or partially algorithmic procedures not covering all the solution of a given task, is accompanied with at least two problems:

- procedural knowledge is harder to be represented (in comparison with static knowledge), and therefore its transmission to learners is more difficult in both traditional frontal education and in e-learning systems,
- internalization of procedural knowledge is hard to be evaluated; the achieved level of procedural knowledge can not be verified by checking only results of its utilization (while
the static knowledge item like name of novel, or date of battle can be simply checked, the correct result of solving equation could also be the side-effect of several mistakes).

This paper extends the ideas from [Olshevicová 2005a, 2005b, 2006], where the Topic Maps-based portal of educational resources was suggested with the aim to offer the repository of knowledge items of different types and formats, together with their organization on the principles of topics and relations that are relevant for given resources. The presented portal builds on the Topic Maps standard (Biezunski 2001; Garshol 2004; ISO/IEC 2000; Ontopia; Park 2003; Pepper 2000). Applications designed on the Topic Maps standard reuse domain models (i.e. domain concepts and relations) as skeletons to which the particular information and knowledge resources are linked (e.g. using the hypertext link). The weak point of the domain models is that they can not capture the procedural knowledge related to domain concepts. This fact had motivated our paper that is focused on analysis of support of representation knowledge of different types for the purpose of relation to e-learning systems.

2. Categories of knowledge

The ontology-based systems operate with concepts. For the purpose of education, it is important to differentiate among knowledge types, related to a given concept. At least following four categories of knowledge can be indentified, each of them can be explored with respect to ontologies:

1. **Static knowledge**, that describes the concept and that can be captured either directly in the ontology, or using the mechanisms that enhance the representation possibilities of ontologies, such as Topic Maps standard (ISO/IEC 2000).

   Examples of static knowledge related to concept of triangle are:
   
   - Triangle is a kind of polygon.
   - There are three subclasses of a class “triangle” according the lengths of sides: equilateral, isosceles and scalene.
   - Triangle has got three vertices and three sides.
   - The sum of the internal angles is equal to 180º.
   - The warring traffic signs are often of the triangle shape.

   Examples of static knowledge related to concept of admission exam are:
   
   - Admission exam is a subclass of a class “exam”.
   - There are subclasses of a class “admission” according the type of institution: college admission, university admission, admission to professional chambers.
   - Admission exam may be composed of several parts (e.g. written, oral, practical exam).
   - Attributes are: starting date, evaluation criteria, duration.

2. **Procedural knowledge** about the concept is too complex to enable sharing through models based on ontologies. Procedural knowledge item can be characterized by related concepts from the ontology, but surely such a description does not cover all its features.

   Examples of procedural knowledge related to concept of triangle are:
   
   - Calculation of the area of triangle using different approaches, e.g. analytic geometry where the coordinates of vertices in the n-dimensional space are given, or using different formulas such as Euclid’s, Pythagoras’ or Heron’s formuals, or in experiments based on completing the square or rectangle that contains the triangle.
   - Planimetric construction of the triangle in situation that few parameters of the triangle are given, e.g. the lengths of two sides plus the size of their arc.
   - Location of the circumcenter (the centre of a circle passing through the three vertices of the triangle).

   Examples of procedural knowledge related to concept of admission exam are:
   
   - Sorting of applicants according to the results.
   - Organization of the event.
3. **Advanced skills** related to the concept are those that expect involving knowledge from different domains or application of more complex experiences or insights. Advanced skills can be understood as a combination of procedural knowledge and problem specific deep knowledge; therefore can not be captured in ontologies directly.

Example of advanced skills related to concept of triangle is:
- Exact calculation or estimation of the area of a natural object that can be abstracted to a triangle or can be decomposed into several triangles.

Examples of advanced skills related to concept of admission exam are:
- Setting of successful admission criteria for all parts of admission exam, according to number of applicants, number of free places, and significance of different parts of the exam.
- Processing results statistically.

4. **Common-sense knowledge** is ability to utilize knowledge related to concept by person who has no scholar knowledge of the domain. Part of common-sense knowledge can be captured by so called top-level ontologies [CYC] that model general terms. Common-sense knowledge often restrict the validity of other kinds of knowledge, because most of our common reasoning is based on our common life experience of what works in our world, what are common physical characteristics of objects around us etc., but in general, such assumptions do not need to be satisfie.

Example of common-sense knowledge related to concept of triangle is:
- Finding the shortest of two paths in terrain or the planning of how to pass through doors with a large picture by application of knowledge of triangle inequalities.

Examples of common-sense knowledge related to concept of admission exam are:
- Knowledge on differences in course of admission exams in different countries, e.g. one admission exam organized at national level versus admission exams set up and organized independently by each university existing in the country.
- Existence or non-existence of admission exams in the country.
- Society-specific admission criteria, which are not dependent on qualities of applicants.

Example of common-sense reasoning that leads to wrong conclusion:
- A hunter goes 100 km south, then 100 km east, after 100 km north and returns to his starting point – it looks like nonsense, most people would expect him to be 100 km on east from the starting point. But this opinion is based on the expectation that the hunter walks somewhere on the flat area; if we know that the starting point was on the North Pole and therefore the hunter moved on the surface of a sphere, the situation is much clear.

3. **Procedural knowledge representation**

When searching for representation of procedural knowledge, it is possible to reuse results of knowledge engineering. This discipline is focused on the codification of knowledge with the aim to process it automatically and reuse it in expert systems and knowledge-based systems. Knowledge methodologies provide different means for modelling reality, i.e. its static part (conceptualization of problem domain), and procedures.

The process of application knowledge item by individual can be decomposed into several phases. After meeting the task, it is important to understand the task and to detect its objective. Either the objective of the task is defined exactly (e.g. the task is to count the area of triangle), or the exact definition of the task objective has to be discovered (e.g. the task is to count the area of garden of the given polygonal shape, where the polygon can be interpreted as a combination of few triangles). Knowing the objective, an individual has to recognize the need of application of certain knowledge. This process is influenced by the previous experience (e.g. the content of the
latest lessons, of the latest self-studied chapter, the previous solved task etc.) and the knowledge level of individual (e.g. different methods of solving the same task are used by elementary school pupils and by university students).

Capturing procedural knowledge can be realized in several levels, where different granularity of knowledge is caught.

1. **Trigger** indicates the knowledge item. It is a sharable and broadly understandable name, acronym or statement that refers to the knowledge item.

2. **Summary of principle** of procedure enumerates the main ideas of the procedure.

3. **Sequence of important steps**, independent on any formalism, expresses the procedure in such a way that individual can complete the whole procedure from it; those steps that request previous knowledge, are not specified in details.

4. **Sequence of all necessary steps**, independent on formalism, and including all previous knowledge in details.

5. **Personalization** is an optional level, that refers to modification the procedure according the criteria or parameters, specific to the given situation.

The lowest level, i.e. the finest granularity of procedural knowledge representation would depend on agreement about the essential knowledge and skills, such as stated in documents about key competences for lifelong learning [Proposal], [Report], [Tuning].

### 3.1 Example: pyramid of procedural knowledge about the triangle area calculation

1. **Trigger:**
   - name of formula: “Heron formula”
   - unnamed formula in its most common expressing known from textbooks (S = av_a/2)

2. **Summary of principle:**
   - Heron formula: expression of area in case lengths of all three sides are given
   - Unamed formula: expression of area in case lengths of the base and the corresponding altitude are given

3. **Sequence of important steps:**
   - Heron formula: the values has to be assigned to relevant variables in the formula, calculation is processed using knowledge of arithmetics etc.
   - Unnamed formula: the values has to be assigned to relevant variables in the formula, calculation is processed using knowledge of arithmetics etc.

4. **Sequence of all necessary steps:**
   - steps enlisted independently on any formalism, so individual can rewrite the procedure using a current mean

5. **Personalization:**
   - transformation of formula in case that the base and the altitude of the particular triangle are not indicated in the most common way, e.g. symbols used in the assignment are not a and v_a, but r and h_r.

### 3.2 Example: pyramid of procedural knowledge about the sorting algorithms

1. **Trigger:**
   - name of sorting algorithm: bubble-sort, insert-sort, shell-sort etc.

2. **Summary of principle:**
   - bubble sort: two neighbouring elements are compared (and if necessary, swapped)
   - insert sort: the smallest element of the unsorted part of the list has to be found
   - Sorting is an algorithm for processing the list of elements – ordering its elements according a given criteria.
There are instances of a class “sorting algorithms”: bubble-sort, insert-sort, shell-sort and others.

3. **Sequence of important steps:**
   - bubble-sort: the algorithm requests to operate in cycle on each pair of neighbouring elements, to compare them and swap...
   - insert-sort: the algorithm requests to operate in cycle, compare all elements with temporary minimum element...

4. **Sequence of all necessary steps**
   - steps enlisted independently on a formalism, so individual can rewrite the procedure using a current mean, see e.g. [Cormen et al.]

5. **Personalization:**
   - e.g. expressing the sorting algorithm in a given programming language in case that user wants to reuse the algorithm in software project)

4. **Modeling procedural knowledge using CommonKADS**

We suggest creating a general model of procedural knowledge using CommonKADS knowledge engineering methodology [Schreiber et al.]. The model can capture the terms and relations that correspond to different aspects of procedural knowledge and its application in process of education.

Description of procedural knowledge item should involve
- subject categorization of procedural knowledge item, i.e. keywords that enable linking of knowledge item to the ontology of domain (e.g. procedural knowledge of calculation of area of triangle should be linked to concepts of “triangle” and “area”),
- expressing of prerequisites of application of knowledge item (e.g. procedure of calculation of area of triangle is valid only in context of Euclidian geometry),
- determination of necessary previous knowledge, that is requested for application of a given procedural knowledge item (e.g. calculation of area of triangle demands the knowledge of calculating with rational numbers),

**Task catalogue**

In the CommonKADS knowledge methodology (Schreiber 2002) offers a catalogue of tasks, where the basic analytical tasks (analysis, classification, diagnosis, assignment, monitoring, prediction) and synthetical tasks (synthesis, design, configuration, assessment, planning, scheduling, modelling) are described on the level of component reasoning knowledge, organized in algorithms.

**Concepts:**

procedure consists of
- trigger
- attributes – input objects/variables, output objects/variables
- algorithm
- step
  - sequential
  - cyclic while-cycle
  - branches / bifurcating ...
  - content of the step – in meta-langauge; formule, expression,...

**Relations:**

previous step – next step
general step – specific step
5. Conclusion

Acknowledgement

The research has been partially supported by the Czech Grant Foundation, Grant No. 402/04/2140 KNOWMEDIAS.

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