Web-Oriented Educational System for Supporting Students' Learning Activity Based on Cognitive Prototypes

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Abstract: This article presents a Web-oriented Educational System (ES) based on prototypes of human cognitive structures (CS) which major goal is stimulation of students' independent work. The theoretical foundation of the system comes from cognitive science, particularly from the Prototype Theory that declares that there are so-called cognitive structures in the mind - mental representations on which human thinking is based. This work is a step towards externalizing human CSs and decide if it is expedient to leverage their prototypes as a basis around which students' learning activity on knowledge acquisition should be organized. Earlier, we determined a data structure that was named cognitive prototype (CP) as a natural knowledge pattern referring to human CSs. We have developed a web-based application as an educational environment for CP-based organizing and supporting both teaching and learning processes. Teacher's module is designed as a tool to assist in describing science objects and concepts in terms of CPs and supervise students' independent work. The latter is built around training exercises incurring from the data structure of CP. Here are two principled aspects: 1) automatically and randomly generated training exercises for students to be done and 2) the exercises are based on knowledge patterns corresponding to the human CSs, which is going to enhance students' knowledge digestion.

Key words: Cognitive structure, knowledge pattern, training exercises, UML-model.

1. Introduction

Currently, e-learning becomes more and more interdisciplinary and computer-based educational systems for e-learning are being developed at the intersection of science by specialists in different areas such as knowledge engineering, information technology, artificial intelligence, educational psychology, cognitive linguistics, etc. Significant advances in cognitive science for the last two decades made it possible to implement some theoretical points into practice of teaching and learning processes. Particularly, most work in cognitive psychology [1] assumes that human mind has mental representations analogous to computer data structures such as logical propositions, rules, concepts, images, and analogies that play a crucial role to understand the mechanisms of human mental processing and information perception. Another name for the mental representations is cognitive structures (CS) that according to Shavelson [2], [3] appear to be hypothetical constructs showing the organization of the relationships of concepts in memory. Many research studies [4] have clearly demonstrated the importance of CS, which refers to how an individual arranges facts, concepts, propositions, theories, and raw data at any point of time. In this aspect, Snow and Lohman [5] consider concepts as the building blocks of meaningful learning and retention of instructional materials. Our main presumption is that knowledge acquisition comes faster if educational knowledge is represented in accordance with human CSs. Therefore, if we organize students' learning activity around learning materials in form of human generic CSs, we suppose to develop students' existing CSs, facilitate the learning and retention of new subject matter, enhance their knowledge digestion, and, eventually, attain a higher level of academic performance.

The objectives of the work are:

- to propose a data structure of cognitive prototype (CP) embodying an approximation of human native CSs to become a basic component for knowledge-driven knowledge bases and knowledge representation for students in computer-based educational systems;
- to elaborate an UML-model of CP as a repository to store CP-based knowledge in object-oriented database;
- to develop an educational system as a web-based application for the supporting both teachers' (course designers') work on creation the educational knowledge bases based on CPs and students' independent work as a set of training exercises incurring from CP-based knowledge patterns ;

The paper is organized as follows: First, we briefly describe our work on externalizing the cognitive prototype structure as the most recurrent data structure from workbooks and concept maps about science education, mainly biological and medical education. Second, we present a UML-model for storing in database educational knowledge based on the CPs. Third, we present a software for e-learning, whose knowledge base is grounded on CPs. The application is divided into two main parts: teachers' toolset for developing the etalon model of academic subject knowledge and students' independent work module. Sequentially, we describe both parts of the software and give some screenshots of it for the better understanding of its capabilities. Finally, we discuss advantages and disadvantages of our approach of learning process organizing with the assistance of the developed educational system and the direction of our future work. The novelty of this paper is a new vision on educational declarative knowledge representation corresponding to human cognitive structures and a new educational software for supporting teaching and learning processes based on CPs.

2. Related Works

All above shows high interest to CSs in cognitive science communities with its application to the field of education. New educational systems incorporate the latest advances in cognitive science. As pointed out by Caravantes and Galán [6], some of them employ estimated cognitive parameters of learning, while others develop computing architectures that stimulate mental processing of students. There have been a couple of methodologies embodied into computer applications to examine, analyze, assess and track changes in learners' CSs in order to help instructors to organize learning materials, identify knowledge gaps, and relate new materials to existing slots or anchors within the learners' CSs. In other words, to have a picture to correct learning paths for students. For example, HIMATT toolset developed by Ifenthaler, Pirnay-Dummer and Seel [7], [8] is web-based assessment and analysis platform included different techniques to diagnose CSs. Some issues that have yet to be resolved include identifying reliable and valid tools to elicit the external representation of internal cognitive structures and the actual analyzing of the structures themselves [8], [9].

Another direction of exploiting CSs in education is concept mapping (CM) technique developed by Novak [10], which is graphical tool for organizing and representing educational knowledge. A CM chart is a way of visualizing educational concepts and interrelationships between them. Its effectiveness in biology education was demonstrated by Preszler [11] and Kinchin [12]. CMAP Tools [13] is an educational software based on this technique to help instructors to create CM charts in order to facilitate student's perception of learning materials. Along with many benefits of this technique of representing learning materials, there are some principle drawbacks. Most of CMs according to Irvine [14] include some aspect of subjectivity, i.e. concept maps made by different teachers look differently even though they describe the same knowledge structure. Moreover, variety of casual types of semantic links in a CM diagram may confuse students as they may not know how to interpret it correctly (one explanation for this is a student's lack of meta-knowledge about the knowledge to be acquired). It complicates and in some ways restricts the possibility of transforming a CM to full educational ontology to be able to automatically operate knowledge for educational purposes in computer-based educational systems.

There have been also some noteworthy ontology-based learning systems to assist learners' navigation in concept maps, for example, ORALS developed by Chu, Lee and Tsai [15], [16]. The systems provides online editing ontology and rules in web pages and reasoning mechanism to assist users' learning. All the searching and reasoning results are listed and shown by visualizing in CM.

The idea of the computer-based training was externalized in a class of educational systems called Intelligent Tutoring Systems (ITS) that is designed to simulate a human tutor's behavior and guidance. The software offers exercises to which students provide detailed responses. Examples of such systems are Cognitive Tutor developed at Carnegie Mellon University, the Andes Physics Tutor developed at Arizona State University, ASSISTMENT developed at Worcester Polytechnic Institute. Being narrowly focused on a specific area of a domain, mainly in such well-formalized areas like math, geometry, physics, IT, etc., these systems require many efforts to enter the specific information for each course or area of study and design training exercises. At the core of knowledge bases of such systems is overwhelmingly mathematical formula language and formal logic. Among other challenges in ITSs that remain is effectiveness in tutoring [17]. The feature of our approach is focusing on poorly-formalized domains like biology, healthcare or related with it subjects and using knowledge patterns referring to human CSs as the basis for both domain knowledge base building and training exercises building incurring from the patterns. CP is to formalize branchy knowledge in these areas and make it processable for computer-based instruction including automatic generation of training exercises. With such the system, it would be possible to help students acquire natural knowledge patterns and foster them to work through learning materials at the stage of their independent work at a distance in a web-based environment.

3. The Cognitive Prototype

The Prototype Theory is a cognitive science theory developed by E. Rosch in the early 1970s, with the help from other experts in the field of cognitive psychology. In Rosch's theory, people categorize items and concepts based on a prototype or ideal representation of that category. Expanding the Theory Margolis and Laurence [18] state that most concepts are structured mental representations that encode the properties that material objects in their extension tend to possess. In order to find externalized prototypes of human CSs we thoroughly scoured many workbooks [19] mainly about science education (biology, histology, embryology, etc.) written by different authors (I. E. Alcamo, R. F. Kratz, M. D. Giuseppe, Jane B. Reece, et. al.) and CMs in order to find knowledge patterns that teachers, who developed them, had left in those workbooks implicitly. Thus, the workbooks can be envisaged as a yield of teachers' mental work on structuring educational knowledge showing an average teacher's view on material objects of a subject domain. While analyzing various training exercises in the workbooks we noticed a common most recurrent data structure that was repeated quite frequently by different teachers. That structure is shown in the Fig. 1. We determine the Cognitive Prototype (CP) as a general knowledge structure that encapsulates numerous elements of information into a single element and organized into a machine-processable manner. Here, we consider knowledge structure as an elemental unit for representation a piece of subject domain knowledge, rather than an interrelated collection of facts or knowledge about a particular topic. Our CP structure consists of a subject, a strictly defined type of semantic relationships and a suite of elements of cognitive subgroup. CP describes a data structure, which can take different meaning depending on type of semantics. Here, elements might be other objects as well as lexemes expressing features, states, and functions of the subject. The most important is that semantic relationships are strictly defined. The number of semantic relations is limited and their interpretation refers to meta-knowledge, which should be explained in detail to students in advance.

$$\langle\textbf{Node}\rangle ::= \langle\textbf{Concept}\rangle\ \langle\textbf{Semantic relationship}\rangle\ \underbrace{\langle\textbf{Element}_1\rangle\ \langle\textbf{Element}_2\rangle\quad \{\dots\ \langle\textbf{Element}_N\rangle\}}_{\textbf{Cognitive subgroup}}$$

Fig. 1. Cognitive prototype node structure, $N \geqslant 2$ (b).

Learning object can be considered either as an aggregated structure consisting of a set of cognitive prototypes with the same concept in the core but with different semantics or as the whole etalon model of a topic that contains all the CPs in the given context (educational purpose). Thereby, the CP appears to be a basis around which educational knowledge might be gathered and based on which training exercises might be derived. Three types of training exercises were determined: 1) an identification of the subject with the given semantic relationship and a set of elements of cognitive subgroup (CSG), 2) an identification of the type of semantic relationship with the given subject and a set of elements of CSG, 3) an identification of the hidden element(s) of CSG with the given subject and the type of semantic relationship. Work on such exercises not only stimulates learner's mental processing and synthesis of information, but also helps student to acquire and adopt 'true' knowledge structures (in the form of CPs). Thus, CP is a data structure from the database building perspective, and it is a natural pattern of educational declarative knowledge structuring from the pedagogical perspective.

4. Modelling and Developing of the Educational System Based on CPs

4.1. UML-Model of the Cognitive Prototype

Our primary aim was to design such e-Learning environment that would provide the possibility for teachers and course designers to create an etalon model of knowledge domain of their subjects without any need of educational ontology developing as well as automatized production of training exercises in the manner as many workbooks do. The central part for this intention has been assigned to CPs. Provide teachers a toolset for knowledge facts describing. Therefore, the idea was to develop a simple-handed repository for storing, retrieval and manipulation of the etalon model of CP-based declarative knowledge. The UML model of CP is shown in Fig. 2. Here is the universal class of Lexeme, and all classes that are a part of CP are subclasses of Lexeme. Lexeme stores the name of element (object, type of semantics, or an element of cognitive subgroup). It is necessary to provide the common vocabulary for all CPs developed within different courses. The CP class merges an object, a semantic relationship and a list of element of CSG. Every instantiation of the CP class is an etalon homogeneous CP-based knowledge unit, a part of the whole etalon model of a subject knowledge domain, ready to be used in teaching and learning processes. On the diagram, the Relationship class has four extensions which are divided into concepts, functions, features and conditions repositories, i.e. elements of CSG may be concepts, functions, features and conditions. Functions class declares a particular function name and also can store its algorithm in different manifestations: conceptual description, flow-chart diagram, scheme, etc. Features can be envisaged as generic characteristics of an object, similar to an instantiation of class properties in object-oriented modeling. A feature has three components: property name, value and optionally unit. For example, if we want to describe the normal value of blood pressure, we would write 120/80 mmHg, that means there is a property name (blood pressure), value (120/80) and unit (mmHg).

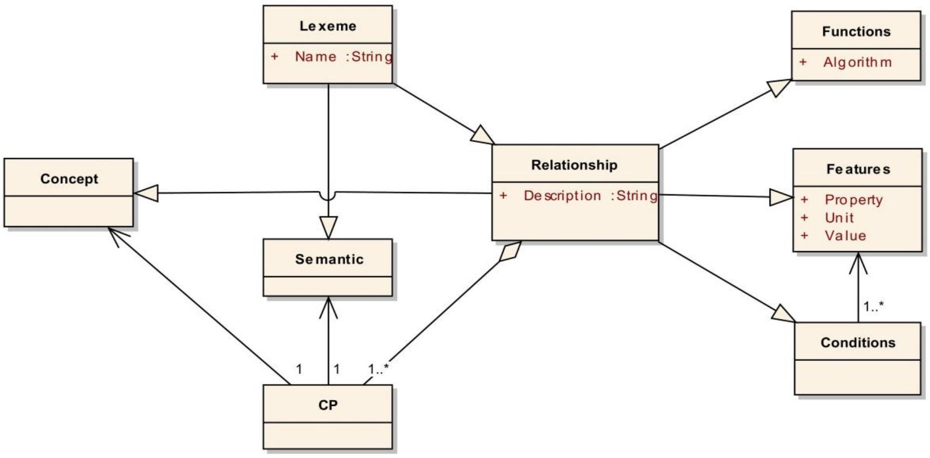

Fig. 2. The UML model for storing CP-based knowledge clusters in object-oriented database. Semantics is hardwired in procedural code (class methods).

Alternatively, if we want to describe the colorlessness of lymphocytes, you should define a property name (color), and a value (colorless). The Conditions class describes certain states of educational objects. An object in a given condition differs in its set of features (values of properties). For example, water is known to exist in three different states, as a solid, liquid or gas which differs in the temperature. If we want to describe the solid state of the object "water", we should link it with the Feature class instantiation, in which there is a property of temperature, value of 0 and unit of C°. The UML model is fully open to extensions, which could be done by inheriting of new classes from the class Relationship (for developers).

4.2. Web-Based Educational Environment Developing

In this section, we describe the developed web-based educational system based on the principles described above. The four requirements for the system were stated:

1) The system should provide a web interface to construct CPs by joining concepts into a full-fledged structure in the drag-and-drop mode.
2) The system should automatically generate training exercises (3 types see above) from CPs and randomly generate a set of them for student's independent work;
3) There must be a toolset for teachers to assess student's independent work in a semi-automatic mode;
4) There must be a possibility for students to do self-testing after a teacher checks their independent work.

The conceptual description of how the system should work is following. There are three phases in the teaching/learning process: preparation phase (teacher or course designer), independent work (student), evaluation work (teacher). At the first phase, a teacher or a course designer creates LOs based on CP. The etalon model (EM) of domain knowledge of a certain subject (or a theme inside the subject) consist of a number of CPs with filled slots as described above. Every theme has its unique set of CPs that adequately represents new knowledge given in it. As the EM of certain theme has been completed, the system should generate the personal suite of training exercises for students to be filled. The sequence of training exercise is stored in the database at the Curriculum class. At the second phase, students work through different kind of learning materials such as handbooks, lecture notes, learning movies, etc. and fill the gaps in their individual training exercises. This work is analogous to the traditional practice of using p-workbooks, except students work in a web environment, guided by our system. At the third phase, a teacher rectifies what students have done on the given topic, the system automatically evaluates their independent work by calculating the percentage of correctly answered questions and then the teacher makes a decision about how well a student is prepared to the forthcoming lab work. At the last phase, a student does self-testing to find out right answers to those training exercises that were not correctly filled in. This stage may be considered as a valuable feedback being an essential part of any instruction.

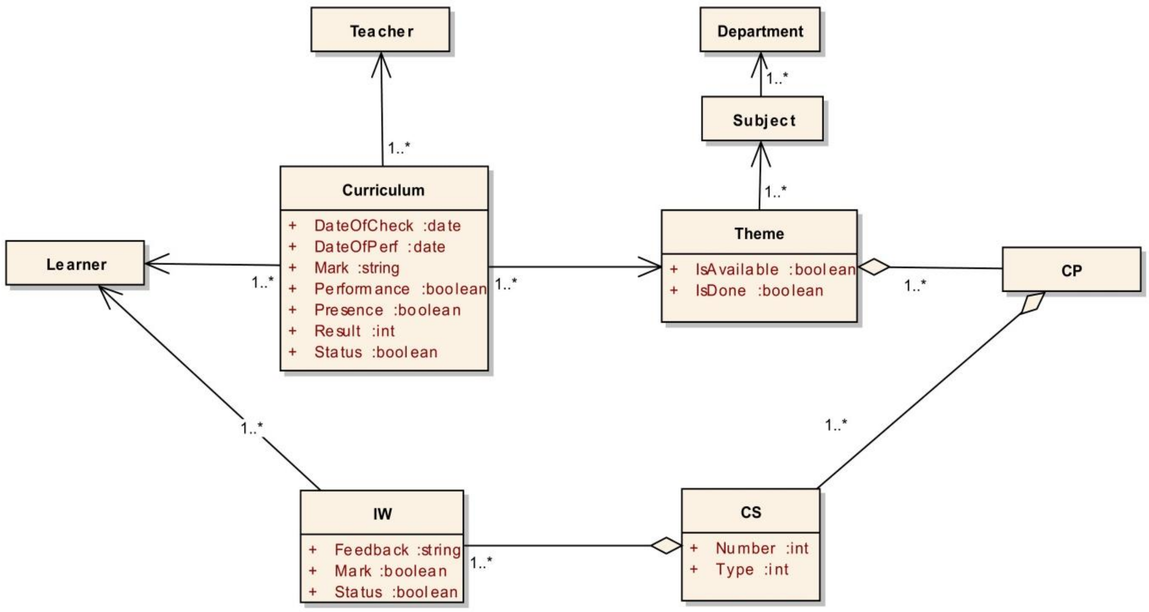

Fig. 3. The class diagram of the educational system based on CPs.

In order to further describe the structure of the system, the UML class diagram of IES based on CPs has been developed as the Fig. 3 illustrates. There we have EM knowledge repository in terms of CPs (the CP class), the CS class that stores all possible variants of training exercises that can be derived from the given CP. The total number of possible training exercises depends on the number of elements in the cognitive subgroups (CSG) of the CP (n). In the elementary case, it would be 2+n (without taking into account the possibility of hiding several elements of CSG). The IW class is to store student's answers and teacher's marks and comments about the fidelity and accuracy of student's work. One of the central part of the class structure belongs to the class Curriculum that reflects all the information about the current posture in educational process. Every entry of it has an individual sequence of CPs for the given student describing the given topic and some information about dates of performance and checking as well as outcomes of checking.

Earlier we highlighted the importance of CSs as the principal factor in the accumulation if knowledge. We believe that if cognitive structures are clear, stable and suitably organized, it facilitates the learning and retention of the knowledge. Opposite, if it is unstable, ambiguous, disorganized, or chaotically organized, it inhibits learning and retention. In order to simulate the CP-structure in the form of web GUI we have developed a separate reusable web-component called WEBCP made from HTML primitives like input buttons and select buttons, which is integrated into one class. Computer-generated training exercises shown in the Fig. 4. A student's web page generates accordingly to his personal sequence of training exercises by assembling all the data about prior work on each exercise. At the caption of the page, the information about the current state of independent work performance is present, specifically the total amount of CP-based exercises in this topic, the percentage of tasks completed by a student and the date of the last work. The percentage of completed exercises is changing dynamically after a next-in-turn input field loses focus and a student have entered at least one letter or numeral. Here we expect students to work through a topic's CP-based exercises in several attempts during the assigned by a teacher preparation time, which can me 2-3 or more days. Each type of training exercises is highlighted with different colors: blue background for the 1st type, reddish background for the 2d type and greenish for the 3d type. Those fields that are designed to be filled in by a student are framed blue.

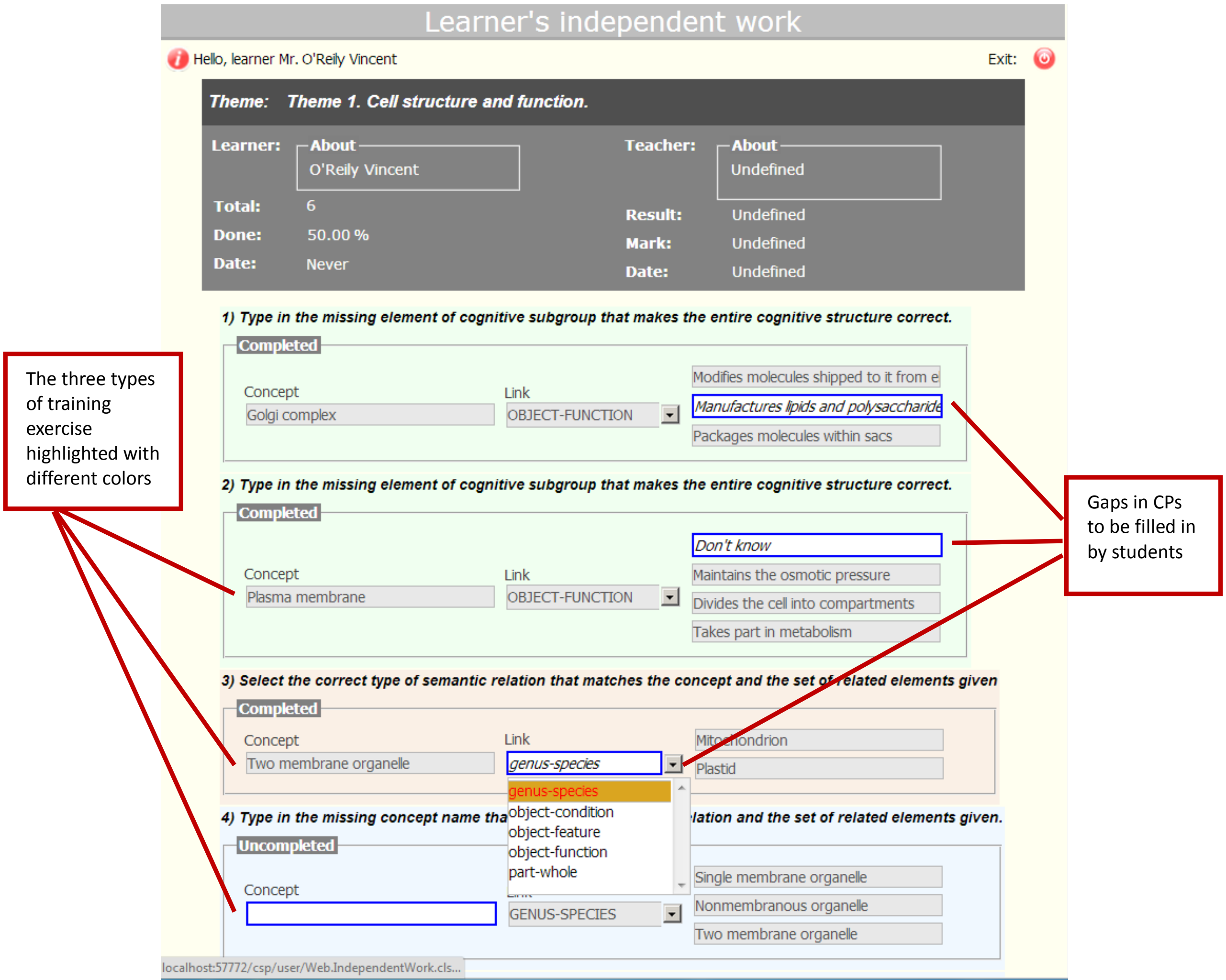

Fig. 4. Web-interface of a student's independent work. The first four exercises for a student on the given topic.

The rest of fields contain etalon data and are disabled to be edited. For the 2d type exercises, the students task is to choose the correct type of semantics from the dropdown list box. A teacher can monitor the students' progress at any time with the help of his administrative toolset. A teacher's evaluating tool looks similar except it is enriched with some rank radio buttons to assess the accuracy of each exercise completed by a student: correct, not correct, postponed. In case the student's answer 100% matches the data from etalon model, the system automatically marks the legend as "correct" to facilitate teacher's control work. Table 1 shows the list of system development technology. The Zen application framework [20] was selected as the main web technology due its simple way to rapidly create complex, data-rich Web applications by assembling a great amount of pre-built object components. This allowed us to use pre-developed web-components to more concentrate on business logic when coding algorithms to track a student's actions, responses and behavior to save more detailed statistics about students' learning sessions. For example, the time, editing actions and number of sessions of every student's work on every topic is kept in the database.

Table 1. The List of System Development Technology

Category	Specification
Object-oriented Database	Intersystems Cache 2013.1 (free for scientific and educational purposes)
Data retrieval language	SQL, Cache SQL
System framework	ZEN
Server logic language	Cache Object Script (COS)
Client logic language	JavaScript
UML developing tool	Sparx Enterprise Architect
IDE	Built-in Studio IDE
Web-server	Apache

4.3. System Implementation

The system is now being tested at the medical biology department of Zaporizhia State Medical University. The biology teachers in collaboration with the authors of the system have developed a CP-based model of parasitology course knowledge that contains approximately 130 CPs that describe the classification, the key features of human parasites and the main symptoms of human diseases caused by these parasites and about 700 training exercises arising from these CPs. All the CPs were merged into seven themes. In average, each theme consists of 20-30 CPs. 20 1-st year students have taken part in the experimental research in which they worked through these learning materials during the spring term as their preparation to the lab work and the module control at the stage of the independent work. The results revealed a high level of students' understanding the key principles of handling the system when working on training exercises. Students admitted the convenience of working from home just via the Internet with no need of any special applications installed except browser. However, some issues have emerged when explaining the meaning of a certain semantics. Therefore, the most misunderstandings were in the 2-d type of training exercises in which students had to decide the correct type of semantic relationships. Consequently, the particular attention must be paid to explain students the essence of each type of semantics to avoid misconceptions. Our next step is to compare the results of module control of two groups of students from experimental and control groups and then to increase the number of students engaged in learning process with the system's assistance.

5. Conclusion and Future Improvements

The developed system in this research illustrates the idea of using knowledge patterns referring to human CSs in learning and teaching processes and points out at the beneficial role of learning activities based on prototypes of CSs. We concede that the described CP-structure is just one of variants of externalized cognitive structures discovered in reflection of teachers' mind internal work materialized in workbooks and concept maps. Anyway, it is a step towards externalizing human mental CSs to become a formal data structure applicable to be used within computer-based educational systems. The feature of the system is that a course designer or a teacher builds CP-based learning materials himself with no need to be an adept in the area of ontological engineering. This is an open software and provides an understandable user interface for students' independent work and elaborate WYSWYG interface for teachers to design CPs. Our experience of using the system has shown a high level of reusability of learning materials in the form of CPs. In spite of the fact, the work on CP-based describing learning objects is quite laborious and time-consuming, each CP, developed once, can be exploited in different courses many times. Our future intentions are to provide a methodology and broad set of guidelines for creating CP-based learning course knowledge models and then to develop a new module for machine-generated tests, which is still an actual challenge despite many efforts from e-learning community in this direction, and, finally, add some aspects of students' adaptation to the curriculum. We expect this software to be not only a toolset to provide an add-on activity to traditional medical and biological education, but also a core activity to stimulate the cognitive processing and synthesis of learning information.

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