COMBINING THE LEARNING OBJECTS PARADIGM WITH COGNITIVE MODELLING THEORIES – A NOVEL APPROACH FOR KNOWLEDGE ENGINEERING

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Abstract: A major challenge in the field of e-learning is to make teaching material reusable. A solution that became widely acknowledged is the learning object approach, and revolves about a set of principles that facilitate the reuse and the distribution of knowledge intended for teaching. Moreover, to build virtual learning environments that do not require the attendance of human teachers and that is able to provide highly tailored instruction, it is necessary to model the cognitive processes of the learner by means of cognitive models. However, these models often avoid the issues of knowledge engineering. Especially, knowledge reuse and knowledge distribution. This article proposes to unify principles of the cognitive modelling theories and those of the learning objects approach, in order to benefit from the advantages of each.

Keywords: knowledge engineering, learning objects, cognitive modelling, virtual learning environments

1. INTRODUCTION

In the context of the knowledge economy, it is increasingly important to keep one's knowledge and expertise up-to-date. Since this situation concerns many workers, a high demand for asynchronous education arises (instruction in asynchronous time and location). Moreover, the achievement of three objectives would benefit to learners and educational institutions. These goals are reducing the development costs of teaching materials and the cost of providing instruction, increasing the sharing of teaching materials between institutions and improving accessibility to education. Distance education and e-learning are the most important means of addressing these challenges. The term “distance education” refers to teaching methods where learners can carry out training activities without having to attend a specific physical location. The subset of distance education that makes use of computer technologies is e-learning. The latter currently shows a strong growth, as a consequence of the current educational context, the opportunity to use high quality multimedia content, and the possible interactions between learners and trainers over the Internet. According to the American marketing company IDC, the size of the e-learning world market which represented US$ 6.6 billions at the beginning of 2002, would reach US$ 23.7 billions in 2006 [8]. Representing knowledge for e-learning purposes requires considering several key aspects such as digital rights management, distribution methods and the easiness for adapting existing content. More importantly, a major challenge is to make the teaching material reusable. A solution that became widely acknowledged is the learning objects approach, a set of principles that facilitate the reuse and the distribution of knowledge intended for teaching. This representation paradigm has become widespread because of the many educational institutions and companies that used it to provide training. However, the contents generally structured and distributed according to this approach are less tailored to each learner. The contents generally consist of Web pages, images and *Java* applets, that virtual learning environment (VLE) distribute as they are. To build VLEs that does not require the attendance of a human teacher and that are able to provide highly tailored instruction, it is necessary to model the cognitive processes of the learner. Several environments based on cognitive modelling theories have proved their effectiveness (for example, see [3]). However, these models often avoid the issues of knowledge engineering. Especially, knowledge reuse and knowledge distribution. This article proposes to unify principles of the cognitive modeling theories, which attempts to model the human processes of knowledge acquisition, and those of the learning objects approach, which takes on the challenges of knowledge engineering, in order to benefit from the advantages of each. The remainder of the article is organised as follows. First, section 2 presents the learning objects approach. Second, section 3 describes the psychological foundations of a cognitive model on which we work. Third, section 4 introduces the computational representation of the model. Next, section 5 reports experimental validations realised with the model. Then, section 6 proposes a methodology to apply the learning objects approach to the model. Section 7 announces further work. Finally, section 8 presents conclusion.

2. THE LEARNING OBJECTS THEORY

The learning objects (LOs) theory describes an approach for knowledge engineering. It relies on the same principles of the object-oriented programming. i.e. structuring learning materials into reusable knowledge objects. Over the recent years, some definitions of LOs – more or less restrictive – have been proposed in the literature. For example, Duncan [5] states that the IEEE defines it as “any entity, digital or non-digital, which can be used, reused or referenced during technology supported learning” [11], Wiley [28] describes it as “any digital resource that can be reused to support learning” and Koper [15] adds that “a fundamental idea is that a LO can stand on its own and may be reused”. To summarise these statements, a LO is an autonomous digital entity which is reusable in training activities. To clarify their role and their nature, the following subsections describe the five steps of the LOs’ lifecycle.

2.1. The creation of an information object

The first step of a LO lifecycle consists in creating an information object (IO). i.e. an electronic document of any format (Web pages, images, Java applets, etc.) and of any type (movie, interactive simulation, figure, text, etc.). Generally, authors of IOs select the format according to the software with which they wants to ensure compatibility. In e-learning, institutions usually opt for Web documents as IOs in order to be able to present them via Internet browsers. Typical examples of IOs are a Web page that explains the process of photosynthesis, an electronic book on linear algebra, an image of a painting by Pablo Picasso and a recording of a musical composition by the famous violinist Nicolo Paganini. Ideally, four principles must be observed when designing IOs. IOs must be (1) autonomous, (2) adaptable, (3) of low granularity and (4) should not be pedagogically neutral. The first three principles fulfil the purpose to maximise the reuse capability of the IOs, the main goal behind the LOs approach. Creating autonomous IOs means to build objects that are free from reference to external contexts. For example, an author who designs an IO that explains how an engine works must avoid including references to other IOs, because IOs can be presented individually. Nevertheless, authors must use decontextualisation sparingly, because as Wiley & al. [29] underline it, decontextualised elements are more difficult to index and have a less clear semantic for a computer. The second principle dictates to create customisable IOs in order to facilitate their integration within particular contexts [18]. The third principle stipulates that adopting a large granularity reduces the number of IOs that can be assembled together. For example, an e-book is less reusable than its chapters or its paragraphs. The fourth and last principle states that an author should not aim at pedagogical neutrality when creating IOs, because it often lowers their teaching relevance [6].

2.2. The addition of metadata

The second step of the LOs lifecycle consists in adding metadata to the IOs. Metadata are structured data that describe other data. Currently, LOM [11] is one of the most important metadata standards. To describe an IO, LOM offers about 80 elements grouped in nine categories. Utility of metadata covers three axes. On one hand, metadata facilitate the localisation of IOs stored in repositories. On the other hand, they inform about how to use the IOs (for example, with regard to copyrights and technology requirements) [4]. Finally, they make possible the automatic selection of IOs by a computer [19]. Metadata are also the element that distinguishes between IOs and LOs. More precisely, adding a learning objective in the form of metadata transforms an IO into a LO. This addition specifies that the IO is intended for teaching purposes [5].

2.3. The aggregation of learning objects

The third step is optional in the lifecycle of a LO and consists in joining several LOs in a package to facilitate their distribution and reuse. For example, in order to simplify their distribution, a professor can group in a package a set of objects, which are necessary for a teaching activity. Since a package is also an IO, if an author adds the required metadata, the aggregate will be also considered as a LO. In the popular aggregation standard IMS-CP [12], a package is a *zip* file which contains LOs and a single file which acts as a table of contents.

2.4. The learning objects sequencing

The fourth step is also optional. It consists in determining the presentation order (sequencing) of the LOs. Although an author can organise LOs in static sequences, some specifications permit modelling complex learning designs. A learning design defines a teaching activity by a set of rules. There rules indicates how to select the next LOs according to the results of intermediate events. Learning designs define also the roles of the various actors who takes part in the activities (learner, support staff, etc.). The most acknowledged specification for LO sequencing is IMS-LD [13] which allows to describe learning designs according to a wide range of approaches of knowledge acquisition (constructivism, instructionism, etc). Various learning designs have been done with IMS-LD. For example, the IMS Learning Design Best Practice and Implementation Guide [13] presents a model of an activity where students take part in a simulation of the treaty of Versailles. The actors are the learners and the support staff. The main roles are those of learner, team leader and teacher. The LOs used are web content resources and the services used are an e-mail server and online conference software.

2.5. The learning objects' delivery

In the e-learning community, the term Learning Management System (LMS) is usually employed to refer to the systems that present LOs to the learners. A LMS is a set of software or a Web environment with which training activities incorporating LOs are carried out [24]. Many commercial and non-commercial LMS exist, such as WebCT [27] and Stellar [25]. Generally the LMS's less adapt their teaching for each learner [24]. The most significant adjustment consists in building a dynamic sequence of LOs [19] that the system presents to the learner (for example, a sequence of appropriated Web pages, following the results of a short multiple-choice test). The weak personalisation of the LMS's can be partially explained by the fact that they often teach complete courses and in most cases, they attach great importance to the contribution of human teachers in the learning activities.

To build a virtual learning environment that does not require the attendance of a human teacher and that is able to provide highly tailored instruction, it is necessary to model the cognitive processes of the learner. Several environments based on cognitive modelling theories have proved their effectiveness (for example, see [3]). However, these models often avoid the issues of knowledge engineering especially, knowledge reuse and knowledge distribution. The LO approach, which takes on these challenges, has been used successfully with knowledge encoded in common formats (webpage, image, etc.). The remainder of the article demonstrates that the main principles of this approach can also be applied to cognitive modelling theories. First, section 3 describes the psychological foundations of a cognitive model on which we work. Next, section 4 presents the computational representation of the model. Section 5 reports experimental validations realised with the model. Finally, methodology to apply the LOs approach is presented in section 6.

3. THE PSYCHOLOGICAL FOUNDATIONS

The psychological representation that we adopt is based on the fundamental principle that to offer optimal teaching, a VLE must be able to identify a learner's intentions, preferences, beliefs and misconceptions. To structure, organise and represent the knowledge, we have been inspired by cognitive psychology theories, which attempt to model the human process of knowledge acquisition. This knowledge is encoded in various memory subsystems not according to their contents but according to the way in which these contents are handled and used. Although there is no consensus on the number of subsystems or on their organisation, the majority of the authors, in psychology, mentions – in some form or in another – three types of knowledge. These subsystems are (1) semantic knowledge [23], (2) procedural knowledge [1] and (3) episodic knowledge [26]. In this paper, we do not discuss the episodic knowledge part of our model since it is the part of our model that records the episodes lived by a person (a history of the use of the two other types of knowledge).

The semantic memory contains descriptive knowledge. Our model regards semantic knowledge as concepts taken in the broad sense. According to recent researches [9], humans can consider about four concept occurrences simultaneously (four dimensions) in the achievement of a task. However, the human cognitive architecture has the capacity to group several concepts to handle them as one, in the form of a vector of concepts [10]. We employ the term described concepts to refer to these syntactically decomposable concepts, whereas we call primitive concepts, the concepts that are syntactically indecomposable. For example, in propositional calculus, "a | F" is a decomposable representation of proposal a, a non-split representation with the same semantic. The concept "a | F" represents a disjunction between proposition "a" and the truth constant "F" (false), two primitive concepts. The symbol "|" represents the disjunction logical operator (OR), and is a primitive concept. In this way, the semantic of a described concept is given by the semantics of its components.

The procedural memory is composed of procedures. i.e., the ways of handling semantic knowledge to achieve goals. In opposition to semantic knowledge, which can be expressed explicitly, procedural knowledge is represented by a succession of actions achieved automatically – following internal and/or external stimuli perception – to reach desirable states [2]. Procedures can be seen as a mean of achieving a goal to satisfy a need, without using the attention resources. For example, procedural knowledge allow us to add automatically "25" and "13" (if our goal is to find the corresponding sum) without being obliged to recall the algorithm explicitly. i.e., making the sum of the units, the one of the tens and twinning the two preceding sums. During the Boolean reduction process, substituting automatically "~V" by "F", making abstraction to the explicit call of the truth constant negation rule (~V = F, where "V" equals "TRUE"), can be seen as procedural knowledge which was acquired by the repetitive doing. In our approach, we subdivide procedures in two main categories : primitive procedures and complex procedures. Executions of the first are seen as atomic actions. Those of the last can be done by sequence of actions, which satisfy scripts of goals. Each one of those actions results from a primitive procedure execution; and each one of those goals is perceived as an intention of the cognitive system.

We distinguish goals as a special type of semantic knowledge. Goals are intentions that humans have, such as the goal to solve a mathematical equation, to draw a triangle or to add two numbers [16]. Goals are achieved by means of procedural knowledge. In our model, a goal is described using a relation as follows: (R: X, A1, A2 … An). This relation allows specifying the goal "X" according to primitive or described concepts "A1, A2 … An" which characterise the initial state. In a teaching context, stress is often laid on methods that achieve the goal rather than the goal itself; since these methods are in general the object of training. Consequently, the term "goal" is used to refer to an intention to achieve the goal rather than meaning the goal itself. Thus, procedures become methods carrying out this intention [17]. To underline the intention idea, the expression representing "R" is conventionally an action verb. For example, "reduce (a, &, ~V) and "substitute(~V, F, (a &~V))" respectively mean the intention to find a simplified form of expression "(a & ~V)" and the intention to replace the "V" truth constant negation "(~V)" by the equivalent "F" false constant in the latter expression. Thus, a goal can be seen as a generic intention where the procedures play the role of methods.

4. THE COMPUTATIONAL REPRESENTATION OF THE PSYCHOLOGICAL MODEL

The computational representation of our model describes each knowledge entity according to sets of slots. These latter associates values to knowledge entities. Values can be either other knowledge entities, or arbitrary data, such as character strings. The next subsection describes the various slots of concepts, goals and procedures.

4.1. The concepts' slots

Concepts are encoded according to the following slots. The “Identifier” slot is a character string used as a unique reference to the concept. The “Metadata” slot provides general information about the concept (for example, authors' names and a textual description of the concept). The “Goals” slot contains a goals prototypes list. The latter provides information about goals that students could have and which use the concept. “Constructors” specifies the identifier of procedures that can create an instance of this concept. “Component” is only significant for described concepts. It indicates, for each concept component, its concept type. Finally, “Teaching” points to some didactic resources that generic teaching strategies of a VLE can employ to teach the concept. Actually, the model distinguishes two types of teaching knowledge. First, there is the generic teaching knowledge encoded in the VLEs (pedagogic knowledge). They are general strategies of teaching such as "to give the easy exercises before the difficult ones" and "to always give hints before giving the solution to a problem". Second, some slots of concepts and procedures (such as the “Teaching” slot) specify didactic knowledge. i.e. generally one or more generic teaching strategies to use as well as the way to instantiate them. This distinction between didactic and pedagogic knowledge is important in our model, because it allow the specification of general strategies for teaching, as well as dedicated strategies for the correction of particular errors or for the teaching of specific knowledge.

4.2. The goals' slots

Goals have six slots. "Skill" specifies the necessary skill to accomplish the goal, “Identifier” is a unique name for the goal, “Metadata” describes the goal metadata, "Parameters" indicates the types of the goal parameters, "Procedures" contains a set of procedures that can be used to achieve the goal, and “Didactic-Strategies" suggests strategies to learn how to achieve that goal.

4.3. The procedures’ slots

Ten slots describe procedures. The “Metadata” and “Identifier” slots are identical to those of concepts and goals. “Goal” indicates the goal for which the procedure was defined. “Parameters” specifies the concepts type of the arguments. For primitive procedures, “Method” points to a Java method that executes an atomic action. For complex procedures, “Script” indicates a list of goals to achieve. “Validity” is a pair of Boolean values. Whereas the first indicates if the procedure is valid and so it always gives the expected result, the second indicates if it always terminate. “Context” fixes constraints on the use of the procedure. “Diagnosis-Solution” contains a list of pairs “[diagnosis, strategy]” indicating for each diagnosis, the suitable teaching strategy to be adopted. Finally, “Didactic-Resources” points to additional resources (examples, exercises, tests, etc.) to teach the procedure.

5. MODELLING THE KNOWLEDGE WHITIN VIRTUAL LEARNING ENVIRONMENTS

Experiments carried out recently showed practical benefits of our approach. The model was used to represent the cognitive processes of learners in a VLE for teaching Boolean reduction [20, 21] and in a software which simulates the realisation of a culinary recipe [22].

Figure 1 illustrates the main interface of the VLE for teaching Boolean reduction. Here, the subject-matter domain is the algebraic Boolean expressions and their simplification by means of reduction rules, which are generally taught to undergraduate students on first cycle of higher education. The goal of the tool is both to help students learn Boolean reduction techniques and to increase the confidence of learners using the tutoring system. Preliminary notions, definitions and explanations constitute a necessary knowledge background to approach the Boolean reduction problem. This knowledge is available to learners in the “Theory” tab of the VLE (the content of the “Theory” tab is not showed on the figure). A teaching session consists in solving a sequence of problems. For example, figure 1 shows the problem “((a | V) & (b & V))”. Boolean expressions can be composed of truth constant “V” (true), truth constant “F” (false), proposals “a,b,c,d,e,f” conjunction operator “&”, disjunction operator “|” and negation operator “~”. The objective of an exercise consists in reducing an expression as much as possible by applying some of the 13 rules of Boolean reduction, such as the disjunction rule of a proposal “a” with the truth constant “False” ((a | F) = (a)), or the De-Morgan rule applied to a conjunction of two proposals (~ (a & b) = (~ a | ~ b). A learner can select part of the current expression in the “Reduction” field and modify it by means of the keyboard or by using the virtual keyboard proposed. The learner must click on the “Submit step” button to validate changes. In the bottom area of the window, the learner can see the last rules applied. In the top corner on the right side, a progress bar shows the global advancement of the teaching session. The “Advices” section at the right of the keyboard shows feed-back given by the system to the learner (hints, advices, etc.).

The knowledge modelled for this VLE is encoded in a single XML file. It contains definitions of concept for each type of element composing Boolean expressions. The primitive concepts are the concepts of truth constant “True”, truth constant “False”, conjunction operator, disjunction operator and negation operator. The described concepts are the concepts of conjunction expression, disjunction expression and negation expression. The model includes also procedure and goals for the 13 Boolean reduction rules and their associated goals (for example, the procedure “ProcedureReduceNegationOfTruthConstant“ and the goal “GoalReduceNegationOfTruthConstant”).

6. A METHODOLOGY FOR STRUCTURING THE KNOWLEDGE IN LEARNING OBJECTS

This section proposes a methodology for organising the knowledge described with our model into LOs. The objective is to facilitate storage, distribution and reuse of the knowledge and to allow specification of metadata that indicate how to handle that knowledge. The first step to obtain LOs is creating IOs. An IO with our model consists of a set of concepts, goals and procedures stored in an XML file. This definition meets the standard definition, which defines IOs as electronic documents. The XML encoding makes the files easily customisable since XML files are encoded as text data.

As mentioned before, the second step of the learning objects’ lifecycle consists in adding metadata to the IOs. For this purpose, we add metadata slots in the specification of our XML file. These slots are useful in three ways. On one hand, they allow importation of definitions from other IO by the specification of their name (aggregation). The aggregation mechanism is a key element for satisfying the requirements of the learning objects approach, because it allows the separation of the knowledge in several files. For example, an author could reuse the procedure of distributing a conjunction over a disjunction “((a & (b | c)) = ((a & b) | (a & c)))” and the procedure of reducing the conjunction of a proposal and its complement “((a & (~ a)) = F)”, to specify in a second IO the procedure of applying the simplification law “((a & ((~ a) | b)) = (a & b))”, a complex procedure that consists in carrying out the two first procedures, one following the other. On the other hand, metadata help ensure the consistency of the aggregation mechanism (a slot is included in each IO to specify its version). Finally, metadata slots can specify other general metadata if needed, such as author(s) name, textual description and copyright.

Moreover, transforming an IO into a LO requires the specification of learning objectives that the IO can teach. This addition guarantees that the IO is intended for teaching uses, but more importantly, it indicates the pedagogical use of the IO. The latter information is essential for software or humans that select LOs to be presented. The following subsection proposes a method for expressing learning objectives in term of the knowledge defined in our IOs.

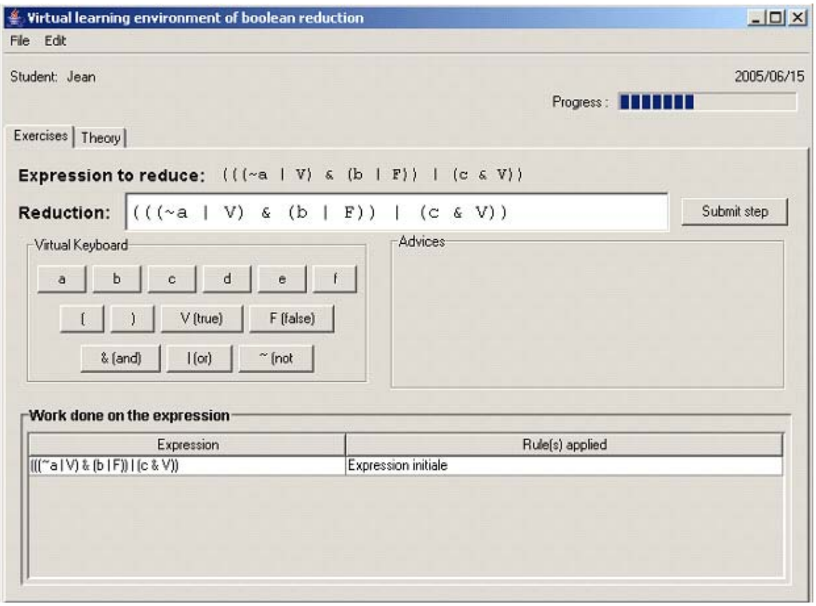

Figure 1. The Boolean reduction virtual learning environment

6.1. Specifying the Learning objectives

A learning objective is a performance description that the learner must be able to show following training [7]. We consider learning objectives that relate (1) to the acquisition of a skill or (2) to the mastery of a semantic knowledge. First, to check the acquisition of a skill is equivalent to testing the ability to attain a goal. The importance resides in learners' ability to realise the goal. The procedures employed are of no importance, since several correct procedures might achieve the same goal. If a learner accomplishes a goal many times with varied problems and without committing errors, one can conclude that the learner has assimilated the corresponding skill. For example, to check the ability to reduce Boolean expressions, a VLE tutor could provide a set of exercises involving the goal GoalReduceBooleanExpression. The procedures used to solve the problems are unimportant to the VLE tutor, insofar as they are correct. To test the acquisition of a more specific skill, such as applying the De-Morgan law to an expression of the form (~ (a & b)), a VLE tutor chooses a more specific goal such as GoalApplyDeMorganLawToNegationOfConjunction.

Second, ensuring the mastery of a concept is more complex. Basically, a concept is an inert structure which describes an object. A concept becomes manifest only during a procedure execution which satisfy the goal using that concept. Consequently, a learner must be able to achieve several goals that used the concept in order to shows that s/he acquired the concept. For example, to test the acquisition of the concept of truth constant “True”, a VLE could test the mastery of the goal to reduce the negation of the truth constant “True” and the goal of simplifying the conjunction of the truth constant “True” and a proposition. This definition of learning objective for a semantic knowledge covers the more traditional definition of researchers in pedagogy such as [14], which indicates that to master a concept one learner must understand the relations that characterise it. For instance, to master the “canary” concept requires knowing relation “color” between “canary” and “yellow” concept and relation “sub concept” between “canary” and “bird” concept. These relations can be encoded as described concept similar as “(color canary yellow)”. An author can add procedures to extract the value from these described concepts and expresses the learning objectives according to the goals associated with these procedures. In summary, the learning objectives that relate to a skill are expressed in the form of a goal to master, whereas those relating to concepts are expressed in term of a set of goals to master. In this sense, our model follows the view of Anderson & al. [3] that VLEs should focuses on teaching procedural knowledge.

We propose six slots to describe a teaching objective in agreement with this definition. The “Identifier” and “Metadata” slot have the same use as for concepts, goals and procedures. “NecessaryGoals” includes a list of goals whose mastery is jointly required to meet the learning objective. “EquivalentGoals” contains a list of equivalence. An equivalence specifies a goal followed by a set of goals equivalent by their joint mastery with regard to the learning objective.

Learning objectives can be added in the heading of our XML files. For example, Table 1 presents the learning objective of mastering the concept of truth constant "True". To attain this objective, the "NecessaryGoals" slot states that it is necessary to master the goal of simplifying the negation of the truth constant "True" ((~ V) = F) and the goal of applying the reduction of a conjunction of a truth constant "True" with a proposal "a" ((a & V) = a). The "EquivalentGoals" slot adds that if a learner masters the goal "GoalReduceDisjonctionWithTruthConstant", it is equivalent with regard to the objective as mastering the goal "GoalReduceConjunctionWithTruthConstant". The decision to make these goals equivalent is a pedagogical decision that could have been made otherwise. For instance, an author could have included both as necessary goals.

7. DISCUSSION AND FURTHER WORK

Initially, our work will focus on creating LOs following the proposed methodology. This task will involve structuring knowledge for some domains already modelled, as well as for new domains. At the second step, we will examine the possibility of integrating existing LOs standards. The XML encoding of our current files facilitates this integration since LOs specifications generally offers XML implementations. We consider using LOM standard for representing metadata. Even though, some metadata can be extracted from the slots of our current LOs, others remain inexpressible with LOM (for example, the description of learning objectives in term of goals, which characterises our model). Another interesting avenue that we explore consists in defining a structure for curriculum representation in term of our LOs.

Table 1. The Learning objective "ObjectiveMasteryOfTheConceptOfTruthConstantV"

Identifier	LearningObjectiveMasteryOfTheConceptOfTruthConstant
Metadata	Author = Philippe Fournier-Viger Creation date = 2005/01/01 Description = The Learning objective of mastering the truth constant "True concept.
NecessaryGoals	GoalReduceTruthConstantNegation, GoalReduceConjunctionWithTruthConstant,
EquivalentGoals	(GoalReduceConjunctionWithTruthConstant, GoalReduceDisjonctionWithTruthConstant)

8. CONCLUSION

In this article, we have proposed an original model for creating reusable units of knowledge that incorporate semantic knowledge, procedural knowledge (the means for manipulating semantic knowledge), as well as didactic knowledge (see section 4.1) which purpose is to teach the semantic and procedural knowledge. By using cognitive structures, this model permit building learning objects that can be used as the basis for providing highly tailored instruction within a VLE. In this way, they constitute a real improvement over the traditional learning objects approach.

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