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ARTICLE

Using Ontological Engineering to Overcome AI-ED Problems: Contribution, Impact and Perspectives

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Abstract This article reflects on the ontology engineering methodology discussed by the paper entitled "Using Ontological Engineering to Overcome AI-ED Problems" published in this journal in 2000. We discuss the achievements obtained in the last 10 years, the impact of our work as well as recent trends and perspectives in ontology engineering for AIED.

Keywords Ontological engineering · Ontology-aware systems · Ontology of learning/instructional theories · Theory-compliant learning scenarios

Motivation

In 2000, the gap between theory and practice in AIED prevented the fluent flow of knowledge from theoreticians to practitioners, especially ITS authors (Murray 1999). Most of the efforts in realizing intelligent behaviors were related to the run-time performance of ITSs such as adaptive tutoring, learner modeling, etc. In other words, intelligent support of development processes of ITSs was mostly out of the focus for most researchers. A major motivation of our paper was therefore to improve the building process of good ITSs by coping with such difficulties. In particular, there was no authoring tool that could help authors build theory-compliant learning scenarios, which was a typical example of the gap between theory and authoring practice. This is partly because of the lack of common vocabulary which was an obstacle to development of AIED systems. Without common vocabulary, it was not possible to

This is not a comprehensive survey paper. It reflects the authors' view of ontology engineering which is mainly concerned with heavy-weight ontology.

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compare existing AIED systems. We aimed at realizing a fluent flow of knowledge from theoreticians to practitioners with an ontology-supported common vocabulary.

Ontologies and Ontology Engineering

In the original paper, we introduced Ontology Engineering (OE) to disseminate ontology-based ways of knowledge base and system building. Ontologies are composed of concepts at an abstract level needed for formalizing the knowledge for intelligent systems. Ontologies help people model the target domain by providing a well-designed vocabulary which promotes coherent ways of system building as well as knowledge sharing. Ontology engineering is a methodology for building and utilizing ontologies and is a successor of knowledge engineering. While knowledge engineering mainly focuses on modeling the heuristic knowledge that domain experts have for performing particular tasks, ontology engineering focuses mainly on the fundamental and long-lasting task-independent knowledge underlying the target domain.

Since 2000, ontologies have become popular and more widely recognized in our community. In particular, they have been extensively used in the Semantic web and semantic technology. Note here that a large part of the ontologies used in the Semantic web are different from those used in what we call ontology engineering, described above. Mizoguchi therefore introduced the distinction between light-weight ontologies and heavy-weight ontologies (Mizoguchi 2003). In philosophy, Ontology means the study of existence. In computer science, an ontology is the specification of concepts, with properties and relations, based on the study of existence. In order to understand similar concepts, one should not care too much about where to draw a boundary between them. In general, boundaries between concepts tend to be vague. The important thing is to capture essential properties representing the typicality of target concepts rather than trying to identify the boundaries between them. Following this principle, on one hand, light-weight ontologies are vocabulary-oriented and are used as metadata for semantic searches in the Semantic web, so they are not required to articulate the target world in an accurate way. On the other hand, heavy-weight ontologies are concept-oriented. They are conceptual artifacts that intend to explicate the underlying conceptual structure of the target world and used for modeling the things and matters in it, and hence they are sometimes required to have philosophical validity. Although heavy-weight ontologies could play the role of light-weight ontologies by providing the set of labels for concepts as a vocabulary, the reverse does not hold. It is also useful to note that the distinction is not a matter of how ontologies are represented in computers. Although either representation is valuable and useful in respective situations, we concentrate mainly on heavy-weight ontologies in this article, to remain faithful to the main message of the original paper.

Good examples of what we mean by "heavy-weight ontologies" are found in the OBO foundry (http://www.obofoundry.org/) co-led by a philosopher Barry Smith in which many biomedical ontologies are developed. All the ontologies are compliant with a top-level ontology BFO (Basic Formal Ontology: http://ifomis.uni-saarland.de/bfo/) developed by Smith and his team, and contribute to the community of bioinformatics. Quality of ontologies in terms of compliance with philosophical theories of ontology is kept very high under the supervision of Smith and his colleagues. He established the International Conference on Biomedical Ontologies (ICBO) in 2009 to promote applied ontology in bioinformatics. People can learn what we mean by heavy-weight ontology from papers published in ICBO as well as ontologies in the OBO foundry. Mizoguchi has been constantly contributing to the ICBO community by developing a new definition of disease called River–Flow Model (RFM) (Mizoguchi et al. 2011)(Rovetto and Mizoguchi 2015) and building a world-first ontology of diseases in terms of causal chains of abnormal states based on YAMATO (Mizoguchi 2010), a top-level ontology he developed.

Another example is found in the activities of Laboratory of Applied Ontology (LOA: http://www.loa.istc.cnr.it/) led by Nicola Guarino established in 2002. Nicola Guarino's group has been a core of ontological engineering from logic and philosophical perspectives. DOLCE (http://www.loa.istc.cnr.it/old/DOLCE.html), a top-level ontology and OntoClean (https://en.wikipedia.org/wiki/OntoClean), a methodology for building good ontologies are remarkable contributions to the community of ontology engineering world-wide. Mizoguchi's team and LOA had an official collaboration under (EU) Marie Curie IRSES Exchange Project, EuJoint: European-Japanese Ontology Interaction during 2010–2012 and published several papers on artifacts, functions and roles in the Journal of Applied Ontology. Nicola Guarino and LOA teams launched the International Association for Ontology and its Application (IAOA: http://www.iaoa.org/) in 2009 to promote applied ontology for information systems. This is almost equivalent to what we call heavy-weight ontology engineering. Mizoguchi joined IAOA as a founding board member. Guarino launched a premier conference FOIS (Formal Ontologies for Information Systems) since 1998, which has been run by IAOA since 2010. Mizoguchi has been contributing to journal of Applied Ontology and FOIS conferences on multiple respects of heavy-weight ontological engineering.

Contribution: OMNIBUS and SMARTIES

In the above-mentioned paper (Mizoguchi and Bourdeau 2000), we claimed that the importance and utility of ontological engineering was to solve typical problems found in building AIED systems. One of the most critical issues that we discussed was how to enable computers to understand and to exploit knowledge found in learning and instructional theories, and we envisioned an ideal authoring system (Fig. 1). We believed that ontology engineering provides us with conceptual tools and theories for dealing with real-world knowledge, which is different from formal disciplines like logic and reasoning which are "content-less". Computational aspects of intelligent learning support systems were our main concern. In 1995, Mizoguchi introduced a three-layer model of ontologies, in which the first layer is devoted to common vocabulary, the second layer to formal definition of concepts and the third layer to operational building blocks such as a task ontology (Mizoguchi et al. 1995) for executing application programs. We claimed that system building should not be ad-hoc but compliant with such an ontology model. In spite of this claim, the reality was not the case. While light-weight ontologies in the Semantic web have become popular and were used for semantically dealing with large data, not many systems compliant with such an ontological model appeared. In spite of this, we expected that heavy-weight ontologies

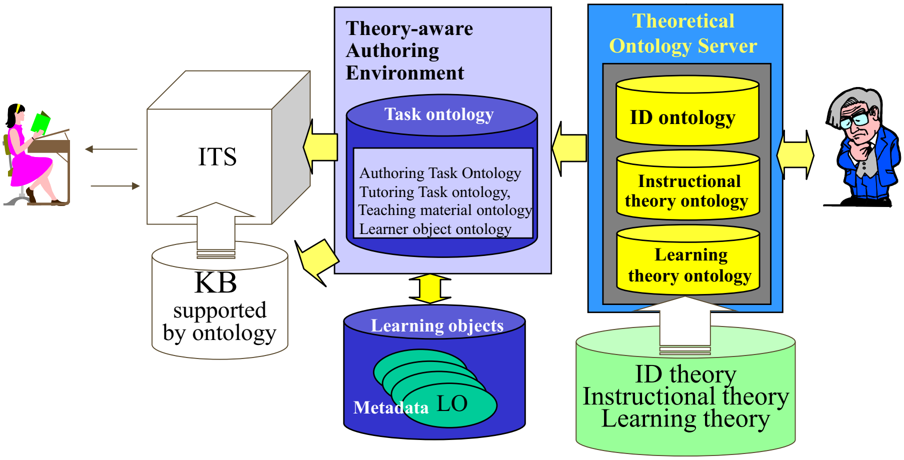

Fig. 1 An envisioned ontology-supported authoring system in the original paper

would show their utility in modeling a content-rich world such as learning and instructional theories and authoring strategies.

Seven years later, OMNIBUS, an ontology of learning/instructional theories produced.

with the Hozo editor,[1] and SMARTIES, a theory-aware authoring system which runs on OMNIBUS, were developed (Mizoguchi et al. 2007; Mizoguchi et al. 2009) (Bourdeau et al. 2007) by the authors' group. The results were described in an article that appeared in the special issue of this journal on Authoring Intelligent Tutoring Systems (Hayashi et al. 2009), and they should be understood as a solution to the problem suggested in the original paper (See Fig. 1). The OMNIBUS ontology and the SMARTIES systems are available on the project web site[2] and fully documented (25 publications). These works complete our endeavor discussed in the original paper because the solution contributes to the clarification of what we really meant by an ontological engineering approach to intelligent authoring systems.

In 2000, a popular solution for dealing with knowledge was rule-base technologies, used in expert systems. Although it worked well for dealing with heuristic knowledge, there was little intelligent technology for appropriately modeling theoretical knowledge such as learning and instructional theories. Enabling computers to understand and utilize theories to help author learning scenarios was almost a dream. We proposed a notion of "theory-awareness" by which we meant a system which is aware of learning/instructional theories so that it "knows" about such theories and can utilize them in building AIED systems.

The original paper suggested a direction to follow with respect to intelligent technology for building AIED systems in a more intelligent manner. In fact, we, the present authors have demonstrated a milestone system which realizes the goal envisioned i.e., "*fluent flow of knowledge from theoreticians to practitioners*"

[1] http://www.hozo.jp/
[2] http://edont.qee.jp/omnibus/doku.php

(Hayashi et al. 2009) (Mizoguchi et al. 2007; Mizoguchi et al. 2009) which was the most important contribution of the original paper.

As explained above, our solution is composed of the OMNIBUS ontology and the SMARTIES system and helps authors build theory-compliant learning/instructional scenarios. One of the main features of the OMNIBUS ontology is that it captures learning and instructional theories as a set of ways of decomposing a goal into a sequence of sub-goals. Simply put, for example, a behaviorist way of instruction is modeled so that the goal of helping learners learn would be decomposed into a sequence of actions like (1) giving stimuli, (2) observing the response, (3) repeating, and the same goal would be decomposed into (1) preparing an environment, (2) putting learners in it, and (3) letting them build knowledge, if the constructivist approach is adopted. This strategy of capturing theories is critical to making theories operational, since these two very different learning theories share the same goal, being "to help learners learn", but are differentiated from each other in terms of the way of realizing the shared goal. Therefore, computers can choose the best way of decomposing a given goal among possible ways extracted by analyzing theories and stored in OMNIBUS ontology. OMNIBUS has 99 ways of goal decomposition extracted from 11 theories/models. OMNIBUS has the framework to include all theories and models, provided that they comply with the specification of the concepts of *theory* and of *model*. In this sense, it is the first and, to our knowledge, the only authoring system that does not constrain or favor one theory over another. The author, a person is making decisions to select the appropriate theories, which are complex and high-level decisions.

SMARTIES is an intelligent interactive authoring system for helping authors decompose the goal of supporting learners down to an executable sequence of learning/instructional actions. It should be considered as a next-generation intelligent system running completely on the basis of an ontology without any heuristic knowledge. At every decision point, it can provide authors with available ways of decomposing a given goal into sub-goals by referring to decomposing ways suggested by the theories stored in OMNIBUS. By repeating such decomposition operations, authors can obtain a tree of sub-goals all of whose decompositions are supported by theories. In this way, they can design theory-compliant learning/instructional scenarios. Another remarkable feature of SMARTIES is that it can translate the decomposition tree into IMS LD[3] code executable by IMS LD compliant tools (Hayashi et al. 2009). OMNIBUS/SMARTIES has thus realized the envisioned theory-aware authoring system.

Concept Formation in the Wild : The Case of the *I_L Event* Concept

Several powerful original ideas were proposed, among them the concept of '*I-L event*', which integrates a '*Learning_event*' with an '*Instructional_event*' in one entity, and represents interaction between the learner and the instructional agent, as well as the activity on each respective side. This proposal was very instrumental in solving the problem of representing learning and instruction separately. In 2002, at the ITS Conference in Biarritz, we presented a communication entitled 'Collaborative ontological engineering of instructional design knowledge for an ITS authoring environment' (Bourdeau, 2002), where we exposed our efforts and progress in building the

[3] http://www.imsglobal.org/learningdesign/ldv1p0/imsld_bestv1p0.html

OMNIBUS ontology. We realized that we were unable to find all the concepts that we needed to build the ontology. This is why we created new concepts, out of necessity. It was triggered the activity we were involved in, as is typically described by Engeström and Sannino (2012) and called 'Concept formation in the wild'. The following tells the story of the emergence of the *I_L event* concept.

As stressed by Engeström & Sannino, forming a concept in the wild does not mean without constraints, and we had strong ones, one of them being to connect our ontology to an upper level or a top level ontology. What does this mean? A good example is the top level concept '*event*' : we questioned ourselves whether *Learning* can be an event, and *Instruction* as well. In the case of a *Learning event*, it should mean that we have a situation where a *Learning agent* learns something. Similarly, an *Instruction event* should mean that we have a situation where an Instruction agent teaches something. But we needed a concept to express what happens when a *Learning agent* and an *Instruction agent* act and interact together (in space and time), so that *Learning* and *Instruction processes* are triggered. We had long discussions about *Learning* and *Instruction*, and the concepts of *event*, *process*, *theory*, *strategy*, *and principle*. We stumbled on the lack of concept to express *Learning/Instruction* as an event shared by both agents, produced by their respective actions and their interactions. Bourdeau was embarrassed that the Learning Sciences literature lacked such a concept, and Mizoguchi worked to create a new one, *I_L event*, as he reports:

> As you know, we first tried to find a solution to our problem in Task Ontology, and were not successful. We had little progress for years. Then, I stopped our plan and tried to find one from another perspective or by another way. And, I suddenly found my idea of function decomposition (Kitamura et al. 2004; Mizoguchi and Kitamura 2009) is applicable to operationally capture learning/instructional theories. The heart of functional decomposition is the interpretation of any function as a goal-oriented interpretation of state change of before and after performance of the function. So, state is the key issue. I tried to find states in our domain. Of course, one is learner's state. But it is not the only one in our domain. The instructor's state, the situation of the instruction process (state of affairs), etc. State used in function decomposition must be singular, I mean, a unified state. But, instruction and learning actions are different and each has its own resulting state.... Oh yes, even if instruction and learning are different actions done by different agents, they can be thought to form a unified pair like you speak and I listen, you write to me and I read it,... You see, then I arrived at the idea that instructional state and learning (learner's) states can be dealt with a pair at any time in terms of which we can represent those events.———

Even if *I_L event* is a good concept in terms of its semantics and of its specification, but the term we used to name it needs improvement to be shared effectively among humans.

A second example is the *What_to_learn* concept. How to express the 'something to be learned'? We tried 'Learning object', but it is a different concept, specific to intentional instruction. What we needed is to express any knowledge, competency, skill that someone is learning, intentionally or not, and with or without instruction. The most unambiguous expression for the semantics that we wanted to have is

What_to_learn, which includes all types of things to learn. Again, although it is a correct concept, the term that we chose could be improved.

In philosophy, Ontology means the study of existence. In computer science, an ontology is the specification of conceptualization, with properties and relations, based on the study of existence. Strangely enough, in our efforts to represent existence, we had to create a new existing thing (concept) in order to represent reality.

Viewed from an ontological perspective, ways of decomposition are entirely supported by concepts defined in the OMNIBUS ontology, that is, there are no ad-hoc concepts or knowledge in them. The concept of finest granularity is a learner's state, which is the foundation for understanding and utilizing various learning/instructional theories, based on our firm belief that any phenomena should be interpreted in terms of state change and learning/instructional theories are not an exception. States contained in OMNIBUS are valid in the sense that they are necessary and sufficient to interpret the 11 models/theories from the perspective of ways of goal-decomposition.

In order to demonstrate operational aspects of ontologies in OMNIBUS, we presented the definition of the class of *I_L event* defined in terms of many fundamental concepts in Hozo together with Learning (and Instructional events) as shown in Fig. 2. We have no expectation that readers try to understand such implementation-level information of *I_L event* in detail. What we want to claim by Fig. 2 is that OMNIBUS contains numerous *I_L events* defined as subclasses of it to model about 11 theories and models found in the literature to enable SMARTIES to "***understand***" existing learning/instructional theories and models for helping authors develop theory-compliant learning scenarios.

Deployment of OMNIBUS-SMARTIES

The work on OMNIBUS and SMARTIES proceeded to the phase of deployment in 2010. One activity is the use of SMARTIES with a help of the first author of (Hayashi and Mizoguchi 2012) in Tochusha (an official community of junior high school

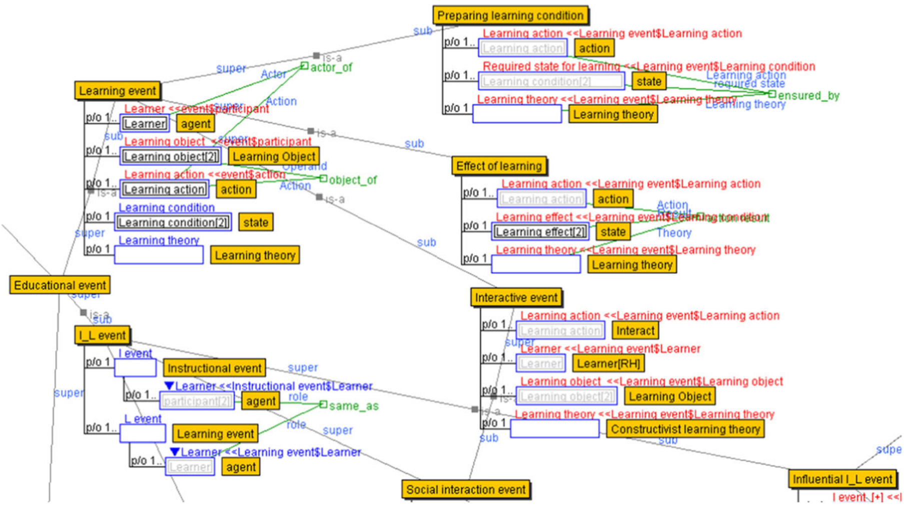

Fig. 2 I_L event and Learning event in OMNIBUS ontology

teachers in Tokyo) for promoting teaching knowledge sharing and development in the subject of social science. They had already established a model scenario at a reasonably high level of abstraction under which all instructional/learning scenarios used in junior high schools in Tokyo will hopefully be built. Another is the augmentation of SMARTIES to enable automatic building of a goal decomposition tree from an input of rough sequence of learning scenario (Kasai et al. 2010, 2014). The new system is named FIMA-light and has been built using rule base technology. It should be considered as an intelligent front-end of SMARTIES. We adopted an existing teacher-friendly vocabulary for describing lesson plans used by teachers, and we map these terms to those defined in OMNIBUS to enable SMARTIES to understand the lesson plans made by authors as input. FIMA-light, generates a couple of the most plausible goal-decomposition trees which are expected to reflect on author's intention hidden in the input lesson plans. The performance was surprising. FIMA-light can generate trees that have about 90 % accuracy of estimation of hidden sub-goals and can give authors opportunities to reflect their design rationale left implicit in the initial lesson plan and to improve the lesson plans with help of the presented trees. Another feature of FIMA-light is that it is domain-independent. In fact, it has been positively assessed using lesson plans of five different subjects made by four (junior) high school teachers.

Methodological Evolution in Ontology Engineering

From the methodological viewpoint, a significant evolution occurred during these years, and is summarized in this section. The first version of our OE methodology (Mizoguchi et al. 1995) that presided the beginning of the OMNIBUS project contained three layers: common vocabulary, formal definition of concepts and operational building blocks such as a task ontology. In parallel, Mizoguchi was working on a top-level ontology, which was released in 2010 under the name of YAMATO (Mizoguchi 2010). With YAMATO, Mizoguchi established the universal and fundamental concepts that would allow him and his team to unify and share a description of the existing: event, process, agent, etc. He then oriented the development of OMNIBUS in this direction, with the constraint of relating our ontology to an top-level ontology, whereby we ensured that the specification at the most abstract level of basic concepts such as *event*, *process*, *system*. This ontology engineering principle has two advantages: on the design level, it provides a common vocabulary, and on the scientific level, it allows for refutation or discussion at the most abstract and even philosophical level.

Impact and Influence

In this section, we review a number of research projects that happened either as a direct result of our work, or were directly influenced by it.

Group Formation in CSCL

What to be mentioned first would be a study on group formation for group learning in CSCL (Computer Supported Collaborative Learning) initiated by Inaba et al. (2000).

Seiji Isotani and Mizoguchi built an ontology of learning theories for group formation by interpreting some theories from the view point of group formation (Isotani et al. 2009, 2010). At that time, group formation was mainly done in ad-hoc ways. The proposed method opened a new direction of theory-justified group formation. The work is still evolving and the recent result is found in (Isotani et al. 2014).

Intelligent Authoring

Lora Aroyo extended her work on AIMS to build Ont-AIMS (Aroyo et al. 2003). She reorganized her work on AIMS which is an advanced authoring model and developed ATO (Authoring Task Ontology) by introducing the notion of task ontology (Mizoguchi et al. 1995). In addition to the original features of AIMS, ATO enhanced it as an intelligent authoring system which can help authors build domain models, course models and instructional models in a unified manner.

Ontology-Based Learning Design

Psyché was also influenced by our views when she described her pioneering work on an ontology of educational theories and their relation to learning design (Psyché et al. 2005). This ontology takes into account learning design (LD) specifications such as OUNL-EML and IMS-LD at the conceptual level (1), semantic web standards such as OWL at the formal level (2), as well as JAVA standards at the implementation level (3). The ontology provided a knowledge base for any IMS-LD compliant authoring systems/LKMS, in order to provide services to authors of LD scenarios. To illustrate this idea, she developed CIAO, a service to the instructional designer. This work is detailed at length in her thesis (https://halshs.archives-ouvertes.fr/hal-00190048/document).

Culturally-Aware Instructional Design

Our work inspired Savard in her doctoral dissertation, where she explored ways to model culture and cultural variables to inform instructional design decisions (Savard et al. 2014). She used a Design-based Research (DBR) iterative approach to identify cultural variables and modeled knowledge regarding these variables via a formal ontology, on the basis of which she created a "Cultural Diversity" knowledge base. Variables were grouped into three categories: *Values*, *Common Practices and Human Interactions*. The *Values* category consists of the following variables: relationship with authority, tolerance for uncertainty, individualism/collectivism, approach towards time. The *Common Practices* category consists of the variables: learning aims, lesson plan, rhythm of learning activities, learning situations, pedagogical communication, cooperation-collaboration, detailed feedback, summative evaluation methods, and the interpretation of results. The *Human Interactions* category consists of teacher's role, learner's role, reaching learning goals and available learning resources. This work allowed her to develop a formal ontology and a "Cultural Diversity" knowledge base, which brings together knowledge regarding five cultures: Quebec, Mauritius, France, Belgium and Gabon.

Ontology of the Technology-Enhanced Learning (TEL) Domain

Bourdeau and Balacheff (2014) worked on defining the terms and the domain of Technology-Enhanced Learning (TEL), a field that intersects with AIED. As claimed by the authors, '*both the concept of Technology-Enhanced Learning and the thesaurus are probed, followed by an attempt to reconcile them within an ontology. Why would we need or wish to have an ontology? The justification is to clarify the status of TEL as a domain, and to formally express a shared understanding of TEL's concepts and structures, and thus help researchers in the field to properly position their projects and papers, share their results, and discover evidence about learning with technology, as well as propose open challenges*'. The TEL meta-project is built on a legacy of the Kaleidoscope FP6 European network of excellence (2009–2012). As a result, the TeLearn open archive was created, dedicated to research in the field of Technology-Enhanced Learning. The Thesaurus was extracted from the corpus of scientific papers contained in TeLearn, and a list of terms was produced with their weight (number of occurrences) and the strength of their links. Based on this list, a dictionary containing definitions written by experts in the field was created (http://www.tel-thesaurus.net/). Subsequently, the TELONTO Project, aiming to propose a conceptual framework engineered as an ontology that can interpret the terms of the TEL Thesaurus and evolve with the development of the field, was proposed. The approach taken to reach this goal consists in connecting the elements of the TEL Thesaurus through the use of the OMNIBUS ontology. The TEL hierarchy has the concept of TEL as its root, and the first level classes are: *Enhancing mechanism*, *Technology*, *Learning*, *Instruction*, *Instructional Design*, and *Theory*. Under the class *Enhancing mechanism* are the mechanisms used to enhance learning. *Knowledge representation* is used to model the learner, the domain, or to represent other kinds of knowledge. *Adaptation* is used to adjust the level of problems, the epistemic feedback, the instructional strategy, or the kind of visualization. The role of *collaboration* is to foster learner motivation and engagement, as well as to implement strategies and tools for social construction of knowledge. *Mobility* is a new way to enhance learning, and *Simulation* a way to enhance inquiry learning, as well as to pursue the study thereof. Under the class *Technology* are the main technologies from the Thesaurus: *Remote Labs*, *Semantic Web*, *Authoring Software*, *Portfolio*, *Standards*, *Multimedia*, *Grid*, and *Data Mining*. In our view, these technologies make sense when associated with an *enhancing mechanism* used by the researchers. Other classes are those imported from the OMNIBUS ontology: *Learning*, *Instruction*, *Instructional Design*, and *Theory*. The authors claim that when integrated with the TEL classes, it will become possible to finalize the ontology. This effort illustrates the feasibility and the benefit to work both bottom-up and top-down to obtain a successful integrated domain ontology.

An Upper Level Ontology of Culture

Blanchard and Mizoguchi built an ontology of culture intended for developing culturally-aware ITSs (Blanchard et al. 2010). Blanchard had initiated a series of International Workshops on Culturally-Aware Tutoring Systems[4] (CATS) since 2008, where Bourdeau and Savard also participated on a yearly basis, while Blanchard and Mizoguchi continued to work on their ontology of culture. Four years later, they

[4] http://cats-ws.org

published a revised and more refined version called MAUOC (More Advanced Upper Ontology of Culture) (Blanchard and Mizoguchi 2014). This ontology was also built in reference to the top level ontology, YAMATO (Mizoguchi 2010). This top-level ontology opens doors to interconnect with operational ontologies such as Psyché's and Savard's, in order to build a complete intelligent architecture for authoring Culturally-Aware Tutoring Systems.

In this section, we summarized several research efforts in which our work has and clearly been instrumental. Moreover, considering the number 394 (Google scholar citations as of August 25, 2015), a large number of researchers have read the original IJAIED paper and either commented it or directly integrated it in their own work. However, the high level of complexity of OMNIBUS-SMARTIES, which makes it so powerful, may have been discouraging for some researchers, in terms of the time and efforts it requires to master it. Another possible obstacle was the use of the Hozo editor, while during that period Protégé became more or less the standard.

Limitations of the Impact and Recent Trends in AIED and in Ontology Engineering

In spite of the authors' efforts in demonstrating how to proceed in the suggested directions for the use of ontology engineering in AIED, research on ontology building has not reached our expectation. Instead, vocabulary-oriented ontologies have been popular in the community and led to interesting activities around metadata in the Semantic Web (SW) including Learning Design (LD). Another LD, Linked Data, provides us with a bottom up approach to integrating and utilizing existing learning objects/resources. A good survey on this topic is found in (Dietze et al. 2013). Both trends are fundamentally different from our approach and sometimes contrast with it. An exception is the research reported in (Sklavakis and Refanidis 2014), where the authors discuss an ontology-driven ITSs in line with our idea of ontology engineering.

Since 2000, the Semantic Web (SW) technology has exploded and been disseminated world-wide including the AIED community. A series of workshops on Applications of SW Technologies for E-Learning (SW-EL'04)[5] was established by Darina Dicheva and Lora Aroyo in 2004 and it has contributed to the promotion of ontology and semantic technology in the community. At the LICEF research center at Tele-university, Gilbert Paquette, Research Chair on Instructional and Cognitive Engineering, and his team have proposed a knowledge modeling framework for instructional engineering, with ontologies, methodologies, tools and applications, that are described in detail in the book entitled 'Visual Modeling for Semantic Web Technologies: Models and Ontologies' (Paquette 2010). Another notable major activity is around LOM (Learning Object Metadata) issues.[6] An example can be found in *LRMI*[7]/Linked Open Vocabularies[8]/*schema.org*, which is currently being active. Concerning SW activities in AIED, activities done by Vladan Devedzic and Jelena Jovanovic are good examples. This topic is well-discussed in (Devedzic 2015).

[5] http://iiscs.wssu.edu/swel_workshops/index.html
[6] http://en.wikipedia.org/wiki/Learning_object_metadata
[7] http://dublincore.org/dcx/lrmi-terms/
[8] http://lov.okfn.org/dataset/lov/schema.org

Conflict Between two Parties

We often see a common conflict between two parties either of which is involved in the process of achieving the same goal, say, building a (ideal) system which necessarily has conflicting properties. A typical example would be knowledge-based systems like expert systems and the SW systems where conflicts appears between high functionality (quality) vs. scalability (quantity). The former adopts a strategy to attain high functionality first putting scalability aside, while SW systems try to attain scalability first rather than pursuing high functionality. Ontology building is not an exception. A good ontology is expected to possess high quality and scalability. By high quality, we here mean not only consistency but also fidelity to philosophical theories and to the target domain as its model. The difference is usually methodological or strategic for achieving the shared goal. One party would like to attain high functionality first in a limited domain, while the other aims to attain scalability as the primary property. The conflict in the ontology engineering community would be better interpreted as a methodological conflict between top-down and bottom-up approaches to building ontologies (See Fig. 3). The issue here is not the question of which party is bigger than the other. Either way may be right. The real issue is two-fold: (1) we do not know the best way to proceed directly toward the goal and (2) neither way might be successful in reaching the goal.

We know performing a top-down way requires us to overcome several difficulties and barriers. This is why the authors presented OMNIBUS/SMARTIES as a solution to the problem discussed in the original paper. Now, feasibility of the top-down way is shown to the community with full documentation. We believe it is the time to expect more people adopt the top-down way to build ontologies.

KLI Activity

The claim of our 2000 paper was that we needed an ontological layer both to pursue research in the domain and to build an authoring system. But this has not happened yet, with the exception of SMARTIES, and the research field is still fragmented and sometimes even discordant. The early 2000's saw the emergence of the Semantic Web, and the tendency to build ad hoc and shallow ontologies. In addition, cognitive

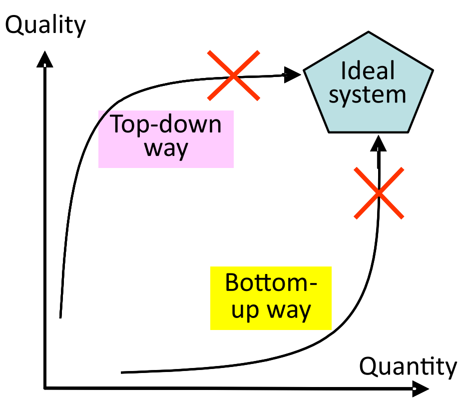

Fig. 3 On scalability

scientists, continued to overlook our work. A major and recent effort to establish a conceptual framework for the ITS domain is reported in (Koedinger et al. 2012) in which the authors propose the following high-level categories: *knowledge components*, *learning events*, *instructional events*, *and assessment events*, which compose the Knowledge-Learning-Instruction (KLI) framework. According to the authors, the articulation of these categories would allow us to predict effective or robust learning. In their article, however, the authors do not express any intention to formalize their framework as an ontology, which would allow the creation of a system (ITS) which would reason and act based upon a shared scientific foundation. The authors did not elaborate a refutation nor a criticism of our work.

GIFT Activity

In the last decade, CMU developed many facets of and tools for Cognitive tutors, as well as a datashop. The University of Memphis developed the series of natural language-based Auto-tutor. In 2009, a serious integration effort started under the auspices of the US Forces lab, uniting prominent researchers in the field in a joint initiative called GIFT (Generalized Intelligent Framework for Tutoring). The group has been working at two levels: conceptual and architectural. At the conceptual level, they have proposed a conceptual architecture, a testbed methodology, and a functional block diagram. Each module of an intelligent tutoring system is the object of a book, with a collection of the various views on this module by researchers: volume 1 is on learner modeling (Sottilare et al. 2013, p.277), volume 2 on Instructional management (Sottilare et al. 2014, p.390), and volume 3 on Learner Modeling (Sottilare et al. 2015). At the architectural level, their efforts tend to integrate the best ITS technologies inside one system that provides services for authoring, managing and conducting research. The team also develops tools to share models and objects. As posted on the GIFT website on Oct. 24, 2014 '*the current GIFT release allow*(*s*) *for a pedagogical engine to select content based on information about the learner*, *skip content based on pre-test information*, *assign remediation based on post-test information*, *assess learners in a practice environment*, *and assign feedback*/*remediation from observations*'. In the GIFT architecture, interface specification is drawn from a set of input/outputs for each module, which is based on an ontology which defines the types and relationships between modules, and each Module has an ontological specification of input/output information (Personal communication from Keith Brawner, 2014–10-17), Although GIFT contains sets of specifications for ITS concepts, it is not in the intentions of the GIFT team to consider an ontological framework that could include all possible events, processes or theories.

As a conclusion to this section, since there has been no refutation of our approach, and since we have made a complete proof-of-concept, we believe that concept-oriented ontology engineering is the best methodology for our purposes, as claimed in the original paper.

Conclusion and Perspectives for OE in AIED

Thanks to the work of our team and of collaborators, we were able to contribute to the community with: 1) a full solution for an intelligent authoring system for ITS, 2) a new

OE methodology with three levels that interconnect and allow a fluent flow of knowledge from theoreticians to practitioners. Our next step is to demonstrate, by integrating OMNIBUS and MAUOC with Savard's operational ontology, how this three-level architecture performs.

We envision a beautiful future in which all theories are archived in an advanced database using ontology engineering in two ways: the first being to use the semantic technology for intelligent search of the related papers with well-organized metadata, and the second to use the *ways of goal-decomposition* we have employed in OMNIBUS to organize and store theoretical knowledge in an operational manner. These two would make theories truly accessible to practitioners. Furthermore, *ways of goal-decomposition* extracted from best practices should be stored in the same platform as those extracted from theories. This is possible thanks to the innovative idea of design philosophy of the OMNIBUS ontology. That is, the notion of ontology of states adequately characterizes situations of learning/instructional processes as well as learner's understanding states about the target subject during the course of learning enables us to capture many theories and best practices in a common framework (OMNIBUS). Expected benefits for potential users and practitioners are considerable.

One well-known issue about ontology is the fact that many of the ontologies out there are left isolated. To say the least, they should be settled under a sophisticated upper ontology, with the benefits that we have demonstrated in our work. That would help people to better understand each ontology by identifying direct super classes of the top-level concepts in the ontologies. Such an attempt might reveal the insufficiency of definitions of the top-level concepts, partially because they would have difficulty in identifying corresponding concepts in an upper ontology.

The last, but not least, issue that needs to be addressed is the methodology to integrate top-down and bottom-up approaches of ontology engineering. Although we know this is a very interesting topic to discuss, it is left as future work or for other researchers as a challenge.

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