Ontology-aware systems in AI-ED research

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Abstraact

This paper discusses long-term perspectives of AI-ED research aiming at giving a clear view of what we need for further promotion of the research from AI and ED point of views. An analysis of the current status of AI-ED research is done in the light of intelligence, conceptualization, standardization and theory-awareness. Then, ontology-based architecture with appropriate ontologies is proposed. Ontological engineering of IS/ID is next discussed followed by a road map towards an ontology-aware authoring system. Heuristic design patterns and XML-based documentation are also discussed.

1. Introduction

Among AI-ED research done to date, several paradigms such as CAI, ICAI, Micro-world, ITS, ILE, and CSCL have been proposed and many systems have been built within each paradigm. And, innovative computer technologies such as hyper-media, virtual reality, internet, WWW have significantly affected AI-ED community in general. We really have learned a lot from our experiences and we may say the results are very fruitful. But, we still need promising directions to which effort should be devoted for further progress of AI-ED research.

AI-ED research consists of the following three major research areas:
(1) Artificial intelligence(AI)
(2) Instructional design science(IS)
(3) Learning science(LS)

Some AI and IS technologies have successfully been introduced into AI-ED community to bring fruitful results in building various Intelligent Instructional Systems(IIS). However, the interaction between AI-ED and AI communities and AI-ED and IS communities have not been very active to date. The authors believe that promotion of more active interactions between AI-ED and AI&IS communities would be beneficial for the future AI-ED research.

This paper discusses long-term perspectives of AI-ED research aiming at giving a clear view of what we need for further promotion of the research from AI and ED point of views. The main topic here includes how to introduce ontological engineering[MIZ96a][MIZ98] into AI-ED research. The next section enumerates shortcomings the current AI-ED research suffers from and discusses about the underlying four key concepts such as intelligence, conceptualization , standardization and theory-awareness. In section 3, we overview what is happening in knowledge-based systems community to learn how ontological engineering plays roles critical to overcoming the problems common to IISs. On the basis of the observations, we discuss ontological engineering of Instructional design:ID knowledge as one of the promising directions to build an ontology-aware authoring environment. Then, we present a road map towards such an environment supported by IS and ID. Finally, some other interesting topics are discussed followed by concluding remarks.

2. Analysis of Current State of the Art of AI-ED Research

Let us first enumerate drawbacks of the current IISs from AI and ED point of views.

(1) There is a deep conceptual gap between authoring systems and authors.
(2) Authoring tools are neither intelligent nor very friendly.
(3) Building an IIS requires a lot of work because it is always built from scratch.

(4) Knowledge and components embedded in IISs are hardly sharable or reusable.
(5) It is not easy to make sharable specifications of functionalities of components in IISs.
(6) It is not easy to compare or cross-assess the existing systems.
(7) Communication among agents or modules in IISs is neither fluent nor principled.
(8) Many of the IISs are ignorant of the research results of IS/LS
(9) Authoring process is not principled.
(10) There is a gap between instructional planning for domain knowledge organization and tutoring strategy for dynamic adaptation of the IIS behavior.

All these issues are content-related ones. In other words, neither inference techniques nor beautiful theoretical formalism can contribute to improvement of the situation. The authors' claim is what we need to overcome these drawbacks is ontology-based architecture with appropriate ontologies, that is, inroduction of ontological engineering. Now, let us analyze the situation in more detail to see the justifications of how ontological engineering can make a reasonable contribution.

2.1 Intelligence

Adaptivity is the heart of intelligent systems. It comes from the declarative representation of what the system knows about the world it is in. In IIS cases, the world consists of a learner and the system itself. So, such a system behaves adaptively to the learner's understanding state. A learner model, which is a representation of system's knowledge about the learner, serves as the source of intelligence. The system can investigate the learner model to adapt its behaviors to the learner. In this sense, the model should be represented declaratively in order for the system to update and interpret it.

What about authoring systems? Do they have such a model or declarative representation of what they know? Unfortunately, the answer is No. This is one of the major reasons why authoring systems are not intelligent. Intelligence of authoring systems is not a specific issue to authoring system research but a general issue common to most AI-ED research, since it is deeply related to the knowledge about how to build IISs.

As discussed above, the source of intelligence of the systems is declarative descriptions about what they know. They can dynamically inspect such declarative descriptions in order to adapt their behavior to situations where they are operating. We could say intelligent systems know what they know and what they are doing.

The next issue is what knowledge authoring systems should possess. Conventional authoring can be viewed as a kind of knowledge acquisition(KA) from teachers/instructors/trainers. This view gives us a few constructive suggestions to improve the performance of authoring systems. We could learn from the research of knowledge acquisition in knowledge-based systems community where KA from domain experts has been the bottleneck of expert system building. One of the major causes of the difficulty is due to the heavy dependence on heuristic knowledge which is hard to acquire, to manipulate and to justify. This is why model-based approaches are incorporated in modern knowledge-based systems which rely mainly on domain theory and model of the target system instead of heuristics.

In our case, analogously, "Model-based approach" is strongly needed to make IIS building more scientific and principled. We need to depart from the "heuristics-based approach" and employ a new technology, that is, ID knowledge to enable the development process to follow instructional design decisions based on principled and theory-based knowledge.

2.2 Conceptualization

Conceptualization is an AI term and consists of objects and relations among them existing in the target world. It is the basis of systems whose performance heavily depends on it. One of the major difficulties common to most of the existing systems is the lack of an explicit representation of the conceptualization each systems is based on. Taking an expert system as an example, it has a knowledge base in it which declaratively represents what it knows about the problem solving in the task domain. The knowledge base can be a source of intelligence when it solves problems. Once a user tries to modify the knowledge base or to reuse some portion of existing knowledge base developed by other persons, however, he/she immediately finds a serious difficulty in doing so. That is, the conceptualization of the knowledge base is implicit as well as underlying assumptions. Even worse, the same terms may have different meanings from his/hers Such information has been rarely represented explicitly, which has been a serious cause of many drawbacks the current knowledge-based systems suffer from.

The same applies to IISs. Few IISs has an explicit representation of its conceptualization. While they know about the understanding state of the learner and have tutoring knowledge, etc., they do not know any concept which their knowledge is composed of. In other words, most of the concetps as well as their primitive actions are hard-wired. We could say such systems are ***illiterate*** because they do not understand the basic concepts. Therefore, such systems never be able to communicate with users(authors) in terms of such fundamental knowledge.

An authoring system should be aware of such conceptualization of an IIS because it creates an IIS by manipulating such concepts accoding to design rationale employed.

2.3 Standardization

Needless to say, industries have attained todays high productivity thanks to standardization of components, say, bolts and nuts. It is a pity that we have no such standardized components in AI-ED community. In order to model target objects, such components would help a lot and facilitate model-based problem solving. Standardization of components does not necessarily imply that of knowledge in general. We are not claiming that all the knowledge should be standardized. Using standardized basic components, one can easily design their own knowledge by configuring them, which is supported by the current engineering production.

Standardization is mainly for providing us with a common vocabulary for understanding what have been done to date with less ambiguity. It never implies any restriction of exploration of the future research activities. The main reason why humans can communicate with each other is we have a common platform of meaning we can rely on and concepts in terms of which we can express our ideas. We can say standardization, at least the effort for standardization to find not only what we can standardize but also what we cannot standardize, is crucial to further success of AI-ED research.

However, one may say AI-ED research is premature to establish a standard. If “standardization” is a bit too strong, we could use the term “shared vocabulary”. It sounds much more softly and acceptable. Specification of functional components should be described in terms of common vocabulary. The problem, however, is the terminology used by teachers, authors, and developers are different from each other. As is discussed above, implemented systems do not understand either of the vocabularies. In short, all the four participants, three humans and one computer, do not share common vocabulary. This has caused a lot of misunderstanding.

Even among human participants, furthermore, when they start discussion on comparison among several IISs of different domains, it is not easy for them to properly perform the comparison because of the different terminologies used in the respective systems.

The same applies to communication among component modules in IISs. Because no common functional specifications and no common vocabulary are available, the components can not communicate with each other properly. This is one of the serious preventive factors of reusability of them.

2.4 Theory-awareness

Expertise is composed of heuristics and domain theories in general. Once it is extracted and is at hand, heuristic knowledge is easy to implement and resulting systems usually works well. Many knowledge-based systems have been built employing heuristic knowledge. One of the shortcomings of heuristic approach is that it is not principled and it ignores existing theories. Another way of building a knowledge-based system is to use domain theories which are in general objective and convincing. People can easily accept such systems that are based on theories.

Issue here, however, is that all the theories in many of the theory-based systems are built in in the procedures. Not the system but the developer knows the theory. Such a system cannot be said to be “theory-aware”. Authoring systems, which are kind of meta-system in the sense that it generates IISs, need to be “theory-aware” to be intelligent. Rich accumulation of instructional and learning theories should be used to authoring systems knowledgeable. Declarative representation of those theories enables them to be called “theory-aware”.

2.5 Summary

Making systems intelligent requires declarative representation of what they know, conceptualization should be explicit to make authoring systems literate and intelligent, standardization or shared vocabulary will facilitate reusability of components and enable sharable specification of them, and theory-awareness makes authoring systems knowledgeable. Then, the next problem is how to find a solution which satisifies all these requirements. The knowledge systems research in AI suggests ontological engineering could provide us with a solution. Let us investigate what has been happening in knowledge processing community.

3. Knowledge and Ontological Engineering

3.1 Knowledge modelling and ontology

In expert system communitiy, the knowledge principle, “The power exists in the knowledge”, proposed by Feigenbaum has been accepted and carried out with a deep appreciation, since it is to the point in the sense that the importance of accumulation of knowledge is larger than that of formal reasoning and logic in making expert systems to work. This has been proved by the success of the expert system development and a lot of research activities has been done under the flag of “knowledge engineering”. After an initial success, however, people realized serious difficulties in knowledge base technology, that is, expensiveness of building a knowledge base and low reusability of a knowledge base. They tried to deal with heuristic knowledge using simple rule base technology. They did not have any sophisticated methodologies or theories for eliciting knowledge from the knowledge sources, transforming, organizing, and translating the domain knowledge to enable the computer to utilize it.

Knowledge modelling, which is a substitute for rule base technology, is a new technology for overcoming such difficulties. It has made easier to elicit expertise, to organize it into a computational structure, and to build knowledge bases. Examples include KADS project in Europe[BRE94], PROTEGE project in USA[PUE92], and MULTIS project in Japan[MIZ92] [MIZ95]. All these technologies are originated from the idea of Generic tasks[CHA86] and heuristic classification[CLA85]. The underlying idea is to find domain-independent activities which specify ***roles*** the domain objects play in the problem solving process. The latest knowledge modeling research introduces an idea of ontology. Roughly speaking, an ontology consists of task ontology which specifies the problem solving architecture of knowledge-based systems and domain ontology which specifies the domain knowledge. Task ontology has been proposed by one of the authors and it serves as a theory of vocabulary/concepts used as building blocks for modeling problem solving structure [MIZ95] [MIZ96b] [CHA99].

Task ontology provides us with an effective methodology and vocabulary for both analyzing and synthesizing knowledge-based systems. It is a system of terms/concepts in terms of which how human experts perform the task(problem solving) is described domain-independently. Task ontology could be what we need to make knowledge-based systems be aware of what they know about the task they are performing, on what conceptualization the knowledge in the knowledge base is based, etc. Research on ontology from an engineering point of view is called ontological engineering.

Thus, knowledge engineering has developed into ontological engineering[MIZ96a][MIZ98]. It is true that knowledge is domain-dependent, and hence knowledge engineering which directly investigates such knowledge has been suffering from a rather serious difficulty caused by its specificity and diversity. However, ontology research is different. Ontological engineering investigates knowledge in terms of its origins and elements from which knowledge is constructed. Hierarchical nature of concepts and decomposability of knowledge are exploited to deeply investigate primitives of knowledge as well as background theories of knowledge which enables us to avoid the difficulties knowledge engineering has faced with.

By a task, we here mean a problem solving process like diagnosis, monitoring, scheduling, design, and so on. In our context, instruction is a task, as is supporting the learning process. A task ontology is obtained by analyzing task structures of real world problem solving. It does not cover the control structure but do components or primitives of unit activities taking place during performing the tasks. The ultimate goal of task ontology research includes to provide a theory of all the concepts necessary for building a model of human problem solving processes.

3.2 Computational semantics of an ontology

What is the computational semantics of an ontology? Is it just a set of terms? This is one of the most crucial points of an ontology. Contrary to that an ontology sometimes looks just a set of terms, it has richer computational semantics. One of the authors has proposed the following three levels of ontologies[MIZ98].

Level 1: A structured collection of terms. The most fundamental task in ontology development is articulation of the world of interest, that is, elicitation of concepts and identifying so-called ***is-a*** hierarchy among them. These are indispensable to things to be an ontology. Typical examples of ontologies at this level include topic hierarchies found in internet search engines and tags used for metadata description. Little definitions of the concepts are made.

Level 2: In addition to that at the level 1 ontology, we can add formal definitions to prevent unexpected interpretation of the concepts and necessary relations and constraints also formally defined as a set of axioms. Relations are much richer than those at the level one. Definitions are declarative and formal to enable computers to interpret. The interpretability of an ontology at this level enables computers to answer questions about the models built based on the ontology. Many of the ontology building efforts aim at those at this level.

Level 3: The ontology at this level is executable in the sense that models built based on the ontology run using modules provided by some of the abstract codes associated with concepts in the ontology. Thus, it can answer questions about runtime performance of the models. Typical examples of this type are found in task ontologies. Software components in component ware roughly correspond to an ontology at this level. But, they have nothing correcponding to levels 1 and 2.

3.3 Knowledge engineering of authoring

Roughly speaking, authoring consists of "static knowledge" organization and "dynamic knowledge" organization. The former includes curriculum organization with instructional design and the latter tutoring strategy organization for adaptation to the learners. Many of the ITS-related research published thus far are mainly concerned with the latter because intelligent behavior of ITSs emerges not out of curriculum itself but out of adaptive tutoring strategies based on learner model built. This is one of the major reasons why ITS researchers who have strong AI flavor do not pay much attention to instructional design technology and have employed heuristics-based approach to the knowledge organization.

On the other hand, curriculum authoring should be supported by instructional design which is based on instructional science which relies on learning science. These dependencies of several types of knowledge are source of intelligence of authoring systems which are expected to help authors build curriculum systematically and scientifically. Declarative representation of such a system of knowledge enables authoring systems really intelligent.

Note here that not all the knowledge necessary for an IIS cannot be theory-based. Just like a knowledge-based system, a good combination of heuristics and domain theories is necessary in reality. However, the more advancement of ID and IS research is made, the more of the heuristics can be explained and hence supported by theories. ID ontology-aware environments could help find justifications of heuristics. This topic is discussed in section 5 again.

3.4 How an ontology provides us with a solution

First of all, level 1 ontology provides a set of terms which should be shared among people in the community, and hence could used as well-structured shared vocabulary. These terms enables us to share the specifications of components' functionalities, tutoring strategies and so on and to properly compare different systems.

An ontology is also defined as "an explicit specification of a conceptualization[GRU]" which suggests it explicitly represents the underlying conceptualization which has been kept implicit in many cases. A level 2 ontology is composed of a set of terms and relations among them with formal definitions in terms of axioms. Such axioms are declarative, and hence such an ontology represents the conceptualization declaratively. Thus, a level 2 ontology gives the source of intelligence to an ontology-based system.

Another role of an ontology is to act as a meta-model. A model is usually built in the computer as an abstraction of the real target. And, an ontology provides concepts and relations which are used as building blocks of the model. Axioms give semantic constraints among concepts.

Thus, an ontology specifies the models to build by giving guidelines and constraints which should be satisfied. This function is viewed as that at the meta model level. Needless to say, this characteristics is what an authoring system really needs. In fact, we can find some research based on the meta-model function of an ontology[MIZ96c, IKE97, MUR98, CHE98].

A shared ontology is a first step towards standardization. Not only informal definitions of terms/concepts but also intermediate concepts are made explicit by the level 1 ontology. The structuring usually employs ***is-a*** and ***part-of*** links to relate concepts each other. The structure obtained in a level 1 ontology itself represents an understanding about the domain of the developer. It is usually much more informative than definition of a term. An ontology cannot instantly become a standard. An ontology designed by a person gives a test-bed for establishing a standard.

On the basis of standardized terms and concepts, knowledge of the domain can be systematized in terms of the concepts and standardized relations identified in the ontology. This is what we are intending to do in our ambitious plan: building an ontology of Instructional Design which makes an authoring system "ID-theory-aware".

4. Ontological Engineering of ID

While the previos sections are devoted mainly to ontological engineering as an enabling technology, this section is concerned with the ID/IS knowledge, target knowledge of ontological engineering.

4.1 Necessity for an Ontology of Instruction

Although AI-ED researchers can be well aware of instructional theories, they encounter difficulties in implementing systems that can rely on a unified and complete set of concepts and principles. How to bridge the gap between the two? An IIS needs terms/concepts concerning pedagogical actions to ground the functionality onto concrete actions. The justification of an IIS should be given by theories and the source of intelligence of the systems should come from the knowledge bases containing this knowledge. However, idiosyncratic implementation dominates the real system development, and this may be a major source of difficulties in the lack of interoperability between knowledge bases and systems. Dissemination of Instructional Knowledge and the sharing of this knowledge among humans and computers has become a necessity. Easy access to instructional theories is of worth to both human and computer agents: for humans, conventional browsers are enough; for computers, somewhat deeper operationality is required; Ontological Engineering helps specify higher level functionality of IISs; it allows to bridge the gap between human knowledge and knowledge in the knowledge bases. The authors believe that a new direction is needed for AI-ED research in the XXIst century, which could take the form of an Ontology of Instruction, that could pave the way to the building of an ID-aware Authoring Environment for IISs. An authoring agent could explain relevant theories in response to the author's request; it could give the author some possible justifications for teaching and learning strategies from a theoretical point of view. To this end, we envision the building of an Instructional knowledge server on the Web, which could have such support functionality, and be called "Instructional Ontology-aware environment". In order to reach this goal, we see that we first need to extract an ontology from existing Instructional theories and from Instructional Design models.

4.2 What is Instructional Science and what is Instructional Design?

Instructional Science was born in 1966, with Bruner's Theory of Instruction, and has remarkably grown since then with Ausubel, Glaser, Gagné, Merrill, to name a few, and with recent developments in Cognitive Sciences (see ID bibliography, http://www.unc.edu/cit/guides/irg-22.html). It builds upon Learning Sciences (Psychology of Learning, Sociology of Learning, Systems Science), and consists of theories, models and methodologies for Instruction and for Research on Instruction. Instructional Science is a Design Science, as defined by Simon; it has both descriptive and prescriptive components; the prescriptive part forms what is called Instructional Design. Instructional Science contains and builds theories, models and methodologies; the focus of studies in Instructional Science is the interrelationships between four classes of variables: instructional situation, subject-matter, instructional outcomes, and instructional strategy variables [REI94].

Instructional Design is a systemic and systematic process of applying strategies and techniques derived from behavioral, cognitive, and constructivist theories to the solution of instructional problems; it represents the systematic application of theory and other organized knowledge to the task of instructional design and development. Subprocesses include: analysis (of subject-matter, goals and objectives, student characteristics, context and constraints), design (higher level decision-making on strategies), development (lower level decisions on learning and assessment activities and material), evaluation (of process and product), delivery (product and services) and management (of design and of delivery processes). Instructional Design is domain-independent, generic, theory-based; it contains concepts, rules or principles. The state of the art in Instructional Design shows concerns about unification and integration [SEE95, DUC98], as well about taxonomic issues [SEE97], toward a better integration of taxonomic concepts between learning domains - affective, cognitive and psychomotor. Instructional Design is independent from learning paradigms [LEB95], and evolves along with new instructional paradigms. Reigeluth's claim for a new paradigm of Instructional Theory [REI96] contains the following keywords: customization, autonomy, cooperation, shared decision-making, initiative, diversity, networking, holism, process-oriented, and Learner as "King"!

4.3 From Teaching and Tutoring strategies to Instructional Strategies

Can teaching strategies be imported from their natural setting, the classroom milieu, to IISs? Teaching strategies have been studied as strategies employed by teachers in a situation whith the following characteristics: actors are one teacher and a group of students; all meet at the same place in the same time, and regularly, on a yearly basis; their encounters are determined by a school system, and by established relationships (authority); personal development, socialization and instruction are important goals, sometimes prior to instruction; there is a culture a teaching, with a set of expectations, which vary with the culture of a society or milieu, etc. Teaching strategies can therefore be called "knowledge in context", strongly dependent on context. Teaching expertise is defined as problem-solving expertise in the context of a classroom, with two main components: routine knowledge and creative knowledge, both strongly related to the classroom milieu [GAG94]. As a conclusion, Teaching strategies should be reconsidered under the light of "knowledge in context" before being imported into an IIS; moreover, they may be analyzed and selected only on the basis of their relevance for IISs and of congruence; some may be strongly revised or adapted, some eliminated.

Tutoring refers to a situation of one tutor to one or a few students, and etymologically contains the notion of strong guidance toward an explicit goal; the metaphor of the tutor for a plant illustrates the idea of going straight in a direction. Tutoring has proved to be the most effective strategy to ensure learning, as demonstrated by Bloom in his Mastery Learning research, and his challenge to discover strategies as effective for group learning still remains unanswered. Tutoring provided therefore a solid ground for ITS research. When referred to in ITS research, tutoring has a more flexible semantics, meaning actions to be taken by a "knowledgeable" system to support or guide learning by an individual student. However, it remains the field of individual learning, as does traditionnal distance learning.

Individual learning, individual tutoring and asynchrous communication are typical features of a distance learning situation, where two main implications for distance learning systems: extensive macro- and micro-instructional design, and a strong student support system. Distance Learning and Instructional Design are intrinsically related [BOU96], and knowledge gained in distance learning theory and design [MOO96] provides directions toward the design of OLEs. Hybrid systems are what we need to envision, where all actors, students and teachers, share both "live" events in natural settings, and virtual ones, with a system that is aware of both universes, and capable of referring to both in its reasoning and decision making.

The term *telelearning* is used to designate new forms of distance or of computer mediated learning, where the distance is not only distance in space or time as in traditional distance learning, but the mediation in learning activities served by media such as multimedia shared workspaces, multimedia communication, or multimedia servers. Many variations can be found in terms of presence, telepresence, meeting in virtual spaces, interactivity with rich multimedia environments, and extensive human interactions in a virtual world with no limits except access and language. Collaborative telelearning emphasizes the collaborative interaction between students in a virtual world[BOU97]. Instructional Design of Simulations and Labs for Telelearning means interdependent design of learning scenarios and learning environments [BOU98].

There is more to Instructional Strategies than only individual tutoring, and a rich set of appropriate strategies could be known by an intelligent authoring environment, with the conditions for their appropriate use,; this includes new ideas such as Reigeluth's learner-focused instruction with appropriate combinations of challenge and guidance, empowerment and support, self-direction and structure, where learners may choose from methods such as problem or project-based learning, simulations, tutorials, and team-based learning [REI96].

4.4 Instructional Design-aware Authoring

Instructional Knowledge has been used in the field of ITS for approximately a quarter of a century, and experience gained in the building of ITSs shows that they are often curriculum or topic oriented, have sometimes weak congruence between analysis of task and instructional or assessment strategies, lack of awareness of learner context besides cognitive aspects; learner modelling is oriented toward control; existing instructional knowledge is fragmental and sometimes used more to serve technical design needs rather than learning needs. Recent efforts in the AIED community appeared toward ITS-Authoring [NKA96, MUR96, RED97, DUB97, IKE97, CHE98]. Murray's recent review [MUR98] shows trends toward inclusion, if not integration, of four components : Tools for Content, Instructional Strategy, Student Model, and Interface Design.
Given the characteristics of Instructional Design (domain-independent, theory-based), efforts have been made in the last decade toward the modelling of this knowledge [TEN95]. A major effort was conducted at USAF Amstrong Lab in the 80s as leaders in the field gathered during several years with the goal of building a consensual body of Instructional Design knowledge, and of automating the Instructional Design Process : this project, called AIDA increased the awareness of the necessity of a consensual knowledge; other major projects include ID Expert by Merrill, GUIDE by Tennyson, System Dynamics at U.Bergen, SAFARI at U.Montréal , and AGD at LICEF [PAQ96]. Instructional Design knowledge also served as a foundation for building the object-oriented Virtual Campus Environment at LICEF [PAQ95].

Intelligent Authoring Environments that can support the building of ITSs need solid foundations in Instructional Science, with a coherent set of concepts and principles for building quality products. Such environments should provide authors with a choice between long established knowledge and more recent developments, such as Reigeluth's proposal to consider learners as co-designers of their instruction, where "learners have the capability to request the computer system to use some instructional strategies, as well as the computer deciding on some strategies based on learner input" [REI96].

4.5 Designing and Authoring an IIS, ILE, or OLE

An ID-aware Authoring System knows the distinction between designing an IIS, an ILE, and an OLE; it provides the set of requirements and decisions to be made in each case before starting any authoring, in order to have a complete, coherent and congruent product.

Requirements in designing an IIS rely on the knowledge of individual dynamic characteristics as much as of the didactic knowledge; we expect ITS research to evolve toward multimedia and VR technology, e.g. for simulations and labs; it could therefore benefit from being based on explicit and theory-based design principles, e.g. for designing learning scenarios together with learning environments. Explicit statements would be to specify the conditions of learning for which the system has been thought, as: complement, supplement or replacement of teaching.

Designing an ILE requires a different set of decisions, that can refer to either individual or team-based learning, with a philosophy such as situated learning; having fundamentals for a constructivist design for example, helps us in making explicit statements about the design principles used, the authoring decisions made, and about their pedagogical finality and effectiveness [LEB95].

Designing an OLE contains challenges that seem to be particularly in phase with the time spirit as we are stepping into the XXIst century. Being "open" can mean keeping your eyes open, and also being open-minded. What does it mean for an OLE? Requirements for an OLE typically are: 1) to know about external learning events, both those planned and the ones that really happened, 2) to be able to reason, make hypothesis and decisions based on both internal and external events, 3) to be flexible in adapting instructional strategies based on culture or affects.

Instructional Design has the capability to make ITSs and ILEs evolve toward Open Learning Environments as follows : Instructional Design is a process by which learning events can be defined or described, independently of their instructivist or constructivist orientation. In order to prevent the « box effect » of Intelligent Tutoring – i.e. a student interacting « within » a system that has no knowledge of any external event- Instructional Design provides a way to inform the system about external learning events, so that it can take these events into account in its reasoning and decision-making. This bridging could make ITSs more « real » to students, make better learning companions or tutors.

5. A Road Map

The following is a road map towards the new direction. Challenges are threefold: 1) the sharing among **humans,** and through computer technology, of the knowledge we have accumulated thus far. 2) The sharing extended from that among humans to that among **computers**, 3) The operationalization of this knowledge to support the building of IISs.

The first challenge is to have computers mediate the sharing of our knowledge. In order to enable computers mediate humans in knowledge sharing, there needs to be more than an information retriever. If the knowledge is derived from different conceptualization of the world of interest, and unrelated terms are used to represent the knowledge, computers cannot do the mediation. They need to share at least the fundamental conceptualization of the target world with humans, and a common vocabulary for representing the knowledge, in order to do meaningful mediation using the common terms. The level 1 ontology discussed in 2.1 plays the sufficient role for this goal. This would be the first step in our enterprise. It is important to note that "shared vocabulary" does not mean that it denies the variety of theories based on different viewpoints, nor doest it mean standardization of knowledge. The goal is to share primitive concepts in terms such that we can describe the knowledge and theories, in full respect of their integrity. We anticipate that most of the Instructional knowledge could be described in terms of a shared vocabulary. We can see movements related to this enterprise: On-line glossary of ID (e.g., http://garnet.acns.fsu.edu/~www6982/glossary.html) and home page of ID theories (e.g., http://www.cudenver.edu/~mryder/itc_data/theory.html); research on taxonomy of ID knowledge [SEE97] also gives a positive indication. One step further towards the level 1 ontology would make a concrete contribution to the goal.

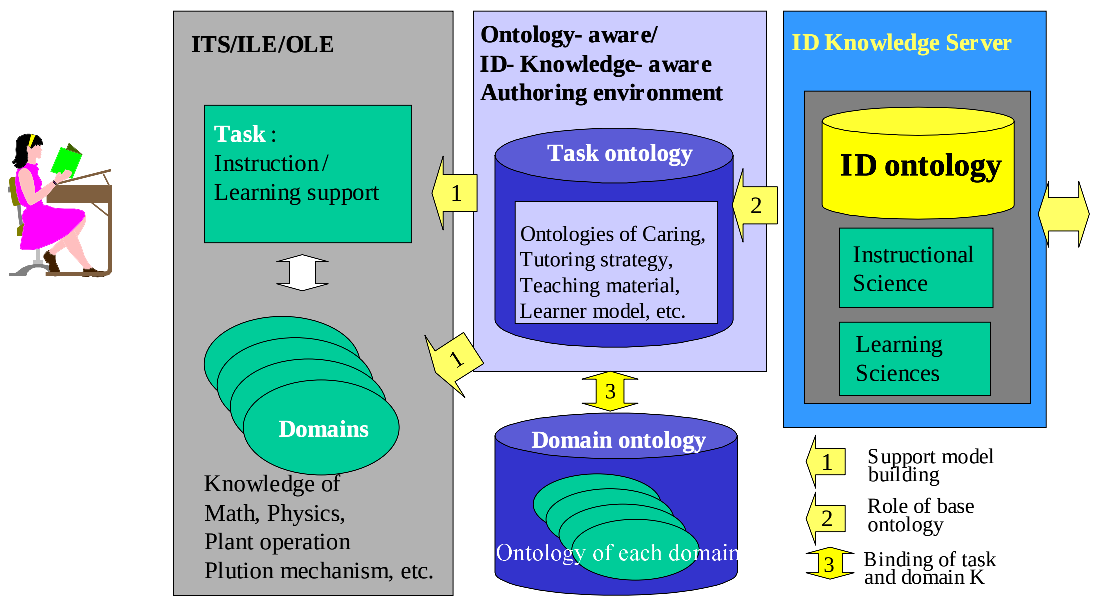

Fig. 1 An ontological diagram of related systems with ID knowledge servers.

The second challenge is to extend this sharing from among humans to among **computers**. Since a shared vocabulary is not rich in meaning - it consists only of a set of common terms structured in terms of is-a and part-of links, computers cannot go deeper because of the semantically poor situation. To enhance computer's intelligence, the level 2 introduces definitions of each term and relations richer than in level 1 using axioms. An axiom relates a couple of concepts semantically, which makes computers partially understand the rationale of the configuration of the world of interest, here learning and instruction.

The operationalization of this knowledge leads to the building of IISs. This requires a level 3 ontology to enable computers to run the code corresponding to the activity-related concepts. Knowledge at this level is mainly concerned with task ontology which contains concepts of action of the system in performing a specific task (instruction, learning support). An ontological diagram of IIS, authoring environment and Instructional Design knowledge server is shown in Fig. 1. When we have a shared vocabulary, then the ID-knowledge server communicates with humans who need help in finding ID knowledge appropriate for their goals; it can give justifications to an ontology in ID-knowledge-aware authoring environments. Thus, such authoring environments can discuss with authors about the appropriateness of strategies adopted with the help of ID knowledge server. Future IISs developed in this way would behave in a seamless flow of knowledge from designers onto learners.

One step into this direction could be to build upon an existing courseware engineering workbench such as AGD (Paquette, AI-ED99), to isolate one set of ID decisions and re-engineer them based on task ontology; a micro-domain ontology could be built from meta-models related to this set. This preliminary work could illustrate and try out the idea of an ID Ontology server.

6. Other promising directions

6.1 Design patterns[GAM77][DEV99][SHI99].

Axioms in an ontology give semantic constraints among concepts besides rigorous definition of concepts. They play a role of constraints which the models built have to satisfy. An ontology-aware authoring system thus can generate warning messages to the authors when a constraint is violated. The constraints could work as guidelines of the model-building process. This is the source of intelligence of such an authoring system. However, we have to pay an attention to the fact that not all the guidelines have to be satisfied by all the model-building processes. As described in 3.3, authoring still requires heuristics. That is, there can be soft heuristic guidelines which are sometimes better to satisfy but not a must, supported not by theory but by experiences and so forth. These kinds of suggestions are not appropriate for representation in the form of axioms. Axiomatic representation is appropriate only for theories.

In the object-oriented paradigm, design patterns are becoming popular recently. To avoid confusion between instructional "design" and "design" patter, in this paper, we call the latter "heuristic desgin pattern". Heuristic design patterns are patterns of class configuration which represent a chunk of information of useful suggestions about design decisions for configuring classes and objects. They are obtained by abstracting the rich experiences of object-oriented modeling and can provide suggestions useful during the course of model building. We can use heuristic design patterns of IIS modeling for the authoring systems on top of the ontology-guided and ID-theory-based model construction to generate helpful suggestions.

The use of heuristic design patterns in our plan is different from that in Object-oriented paradigm, given the declarative nature of an ontology. Heuristic design patterns in an ontology-aware authoring systems are represented in terms of an ontology, and hence they are operational, while those in object-oriented paradigm are not operational because they are informal assuming human interpretation. All the terms appearing in an level 2 ontology are operational in the sense that computers can interpret the axioms associated with the terms used in the design patterns so that applicability of the patterns to the current situations can be checked by computers with appropriate suggestions. Application of dsign patterns to IISs are recently discussed by V. Devedzic[DEV99] and H.Shimizu, et al.[SHI99].

ID knowledge server and a heuristic design pattern server would realize an effective combination of theories and heuristics for intelligent authoring environments.

6.2 XML-based documentation of IS knowledge

XML[XML] is a simplified version of SGML which is a powerful markup language definition language and has been widely used in document description for years. XML is equipped with several powerful hyper-reference functions to fit the internet environment. The good things of XML include that the users can define their own tags to indicate not only structural information of the document but also its semantic information for various uses of the document to enable semantic interoperation. A set of XML tags are a kind of level 1 ontology.

XML is sometimes said to be HTML++ because XML is so flexible that it enables us to present XML documents in ways whatever we like, while HTML documents are used only for the presentation we see in Web browsers due to its predefined tags. A first step of use of the XML tags might be to design metadata of Learning objects which has been done in IEEE LTSC committee P1484[IEE], IMS[IMS] and ARIADNE[ARI]. As a more advanced applications of XML tags might include designing XML tags for making documents to be a live teaching material.

For example, we can design an intelligent instructional player of an XML document as a teaching material by sharing a set of tags for explicating instructional roles of the portions of the document and controlling the interpretation. It could "Play" the XML document adaptively to the performance of the learners with the help of Java applet. Further, we could formalize the set of tags to specify the performance of such instructional players. Intelligent players with plug & play capability with shared XML tags are expected to be promising with Java implementation.

Resource Description Framework: RDF[RDF] enables solider and richer marking than XML. XML with RDF will open a new world of instructional documentation which can produce documents for human interpretation and those for computer interpretation to make them teaching materials. The critical issue here is to design a set of sophisticated tags which we can share as standard. This requires a huge effort but it should be rewarding. Ontological engineering can make a substantial contribution to this enterprise.

7. Concluding remarks

We have discussed ontology-awareness in AI-ED research. The discussion has got started by an analysis of the current status of AI-ED research in terms of intelligence, conceptualization, standardization and theory-awareness which suggest an importance of ontology-based architecture with appropriate ontologies. Ontological engineering of IS/ID was discussed followed by a road map towards an ontology-aware authoring system. Heuristic design patterns and XML-based documentation were also discussed.

The implication of "ontology-awareness" is deep. It is not only for AI-ED research for system building but for knowledge sharing among humans and computers. Most of the existing theories are in the form of informal representation assuming human interpretation. One of the most important merits introduced by ontological engineering is that is enables human to share the theories with computers. Furthermore, it can mediate people to find a minimum agreement.

I can hear some voice saying "It's OK that an ontology represents a shared conceptualization in a community. But, let me tell you that ID is the most dangerous domain to design an ontology because it is almost impossible to find a consensus."

Our answer is: Yes, but, it is the very reason why we advocate ontological engineering of ID. Our claim includes an ontology helps people indentify what they agree on and what they don't. An ontology is not the total knowledge of the target world but is a backbone/skeleton of the target world. Each person could come up with his/her own ontology developed by an ontology editor with sophisticated guidelines. Imagine an "Ontology-mediated agreement-finding system" is available. Then, they start to discuss to find the similar and different portion of them with the help of the "Ontology-mediated agreement-finding system". They can discuss by exploiting the hierarchical nature of the ontologies which help them find easy agreeable general concepts by going up the hierarchy. The ***is-a*** and ***part-of*** hierarchies of the ontology will help people involved in agreement finding notice what are the essential differences between them. Each ontology can be interactively reorganized according to the goals or purposes specified. They might notice what should be stable concepts to make the ID research meaningful as well as what could be left unstable depending on personal views of the world. The important thing is that what they finally get is an ontology which represents the minimum amount of stuff agreeable at the time. It may be far from complete, but it should be a good start to come up with richer agreement.

The authors believe that amalgamation of AI research and IS/ID theories using ontological engineering as a glue will open a new world in AI-ED research. Be aware of Ontology-aware systems!

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